FORESTS IN FLOOD CONTROL

SUPPLEMENTAL REPORT

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ON

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TO PROVIDE FOR A PERMANENT SYSTEM OF FLOOD CONTROL, AND FOR OTHER PURPOSES

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INTRODUCTION

The seriousness of the flood problem has again been borne upon us. Great floods have again ravaged densely populated sections of our country, destroying lives and property. Once again, floods have laid a heavy toll upon the Nation, causing untold suffering and human distress.

Such disasters as those of last March are largely symptoms of man-made troubles and contrary to popular belief, are not in themselves an act of God. Too often the elements alone are blamed for the surging tide of water that swirls into city streets, that tears homes from their foundations, and that covers fertile farm lands with sterile sands. Too often the flood victims say as they clear away the wreckage, that it couldn't be helped. Too often the Nation gives for relief of suffering when similar sums provided for control measures would prevent such suffering.

Disasters such as those of last March, and similar disasters of greater or lesser extent that sweep down the river valleys of the Nation annually, have their genesis in headwaters areas, in the minor tributaries where the waters congregate before they unite to form the river. And it is because the floods start at the point where the storm-waters fall, that foresters have for decades maintained that forests have an important part in flood control.

Foresters have not said that forests control all floods. They have said that if each drop of water were held at the place where it first reaches the ground, there would be no floods. Man cannot by engineering methods alone control major floods in the lower river. Foresters contend that in the control of floods, measures on land are as important as measures in the river, and that through proper land use, through good forest practices, and through close integration of forestry and engineering, the severity of floods can be mitigated, and under many conditions floods may largely be prevented. Foresters believe that there should be no conflict between engineering methods and forestry, but that both should be brought together in a coordinated attack on the problem. Work on the rivers is properly the function of engineers; work on the land is the function of the agriculturist and the forester. With forests at the headwaters, floods would in part, be prevented at their source.

HOW FOREST COVER AIDS IN SOLVING FLOOD PROBLEMS [1]

The question is asked: Does the condition of the forest cover on the watersheds of streams appreciably influence stream flow, and how far may forest management be expected to aid in solving these problems?

[1] See also A National Plan for American Forestry, S. Doc. 12, 72d Cong., 1933. The section on "Watershed and other Related Influences" was also printed separately.

Forest cover in its relation to flood control is considered to include: (1) The trees and tall brush; (2) the herbs and shrubs growing thereunder or in openings in the forest or brush-fields; (3) the litter or fallen leaves, branches, down trees, and other vegetative material on the forest floor; (4) the rich humus of partly decayed vegetable matter at the surface and in the top layer of the soil; and (5) the soil itself. Thus it is the influence of the entire forest cover upon floods and other watershed-protection values which are given consideration, rather than the influence of the trees alone.

There is a rather widespread popular acceptance in this country of the idea that forests and associated or related vegetation exert a favorable influence on floods. This probably had its origin in European experience, and has been fortified by general observation, such as the muddiness of streams flowing from cleared land compared with the clarity of those flowing from woodland, and extreme fluctuations in the rate of streamflow from deforested or denuded land. Only of late has a body of information based on careful observation and experimentation begun to accumulate behind the popular concept of the forest as a regulator of stream flow.

This concept of the beneficial influence of forests has been embodied from the first in the administration of the national forests created from the public domain, and was long the sole basis for purchase of national forests in the East. The act of 1897, which first provided for administration of the original forest reserves, named as a major purpose "securing favorable conditions of water flows." Certain of the national forests of the West—among them the Tonto in Arizona and the Angeles in California—have been created in whole or in large part principally for the protection of irrigation projects or municipal water supplies. The Weeks law of 1911 provided for Federal cooperation with the States "for the protection of the watersheds of navigable streams", and for Federal "acquisition of lands for the purpose of conserving the navigability of navigable rivers." The Clarke-McNary law of 1924 continued the cooperation "with a view to the protection of forest and water resources", and directed that in further purchases "due consideration" be given both to watersheds of navigable streams and those "from which water is secured for domestic use or irrigation."

In direct opposition to the popular idea regarding beneficial forest influences have been the doubts from time to time implied or expressed by various small groups of engineers, geologists, and meteorologists. The Mississippi River Commission, for example in its 1927 plans for controlling floods in that stream, set up grounds "to justify rejection of reforesting as an element of flood control in the lower Mississippi River", and has ignored the possibility that proper management of the 20 percent of the watershed still in forest may reduce flood crests by the critical feet or inches that often spell the difference between mere high water and disaster. Other men of scientific standing from time to time attempt to prove that because forests and similar vegetation are well known to appropriate to their use considerable quantities of ground water, particularly at seasons when streams are low, their influence is detrimental rather than beneficial. In the face of criticism of this character it is desirable to summarize here some of the more important available recent experimental evidence on the relation of forests to stream flow under American conditions of climate, soil, and vegetation.

HOW FOREST COVER INFLUENCES RUN-OFF

Whether the rain and snow falling on any watershed is as fully useful to mankind as it might be depends almost wholly on the character of its run-off. Of that which sinks into the ground—that is, is absorbed by the surface soil or percolates through it to greater depths—the greater part becomes available for the growth of plants useful to man or his domestic animals, or in time appears in streams capable of furnishing fairly constant supplies of water for domestic, industrial, and irrigating use, of generating water power, and of transporting freight. Or it may be stored in natural underground reservoirs available to human use. The precipitation which quickly reaches the streams by flowing over the surface of the ground, on the other hand, causes much erosion and many floods. This general classification of subsurface run-off as useful, and flashy surface run-off as detrimental, is of course subject to many exceptions. Not all vegetation using rain that has penetrated the ground is directly useful to man, and some of this water is lost through chemical combination in the soil and through seepage to great depths. Even subsurface waters when they reach the streams may contribute to floods, and the flashy run-off under some conditions may be stored above or below ground, and thus be prevented from causing destructive floods or being lost to human use during dry seasons. These instances are, however, so exceptional and the beneficial effects for which they are responsible are so slight in comparison with the damage ordinarily wrought by flood run-off that they may be dismissed here as entirely negligible.

Studies of surface run-off from forested areas, and from areas in other types of natural or planted vegetation have been made in Wisconsin. On the silt loam uplands in southwestern Wisconsin [2] with slopes averaging 36 percent, Bates and Zeasman have shown that the proportion of total summer precipitation which ran off over the surface of the ground beneath hardwood forests of varying density averaged 2.8 percent. Wild pastures of native grasses, in which the soil had never been cultivated, showed a surface run-off about 2½ times as great. Cultivation greatly increased the percentage of surface run-off; from cultivated hay fields it averaged 17.7 percent, and from small grain fields, cornfields, seeded pastures, and fallow land it averaged over 25 percent.

H. G. Meginnis of the Southern Forest Experiment Station made a study of run-off from the upland loess soil of northern Mississippi by means of sample plots. At the time of the disastrous flood in the Yazoo River in 1931–32 when 27 inches of rain fell, 62 percent of the rain ran off immediately from the plots located in cultivated fields, and 54 percent from those located in abandoned fields. The run-off during the same period from the plots in an undisturbed oak forest was only 0.5 percent and but 2 percent in a scrub oak forest.

Total run-off can of course be measured only at the foot of slopes, or wherever the precipitation which has percolated into the ground is again brought to the surface by the outcropping of bedrock or impervious soil layers and joins that which has run off over the surface. The volume of streams, compared with the precipitation received by the watershed above the point where stream volume is

[2] Bates C. G., and Zeasman, O. R. Soil Erosion. Wisc. Agr. Exp. Sta. Research Bul. No. 99, 1930.

measured, indicates total run-off only so far as there is no deeper movement of moisture in the soil beneath the stream channel. In the drier portions of the United States stream flow for an entire year may be as little as 6 percent of the total precipitation on a watershed,[3] although averaging more, but in the more humid portions is almost always higher. In the Middle West—Missouri and Illinois, for example—the total run-off as measured by surface flow averages 20 to 30 percent[4] with minima of probably 15 percent. In the East the average total run-off in streams is more nearly 50 percent of the precipitation and rarely drops below 25 percent. King[5] gives the average percentage run-off for Tennessee rivers as 45 percent with extremes of 12 and 66 percent.

The principal factors which influence the normal division of run-off into useful subsurface waters and less useful or destructive surface or flood waters are the character of the precipitation, the geology and topography of the surface on which it falls, and the vegetative cover on that surface. The vegetative cover is the only one of these factors which it is within human power to control. Hence the necessity for understanding how it operates. Forest is the cover on by far the greater part of the United States which is still in natural vegetation and on which important quantities of rain or snow fall. The more important ways in which they bring about their total effect on run-off are discussed below.

Interception of Precipitation

Anyone who has taken refuge under a tree during a summer shower knows that the crown of both evergreen and broadleaf trees intercepts and holds a certain amount of the rain which is later evaporated, but that if the rain is prolonged until the leaves and branches are thoroughly wet, the remainder of the fall reaching the tree drips off, and is not caught but only delayed in reaching the ground.

The Forest Service has recorded rainfall at paired stations inside and outside of timber stands in several forest types. Records of 3 to 5 summers show that a good pulpwood stand of spruce, fir, and some paper birch in Maine intercepted 26 percent of the rainfall; another Maine stand of pure spruce-fir, 37 percent; a dense saw-timber stand of white pine and hemlock in Massachusetts, 24 percent; and a heavy virgin white pine and hemlock stand in Idaho, 21 percent. Briefer studies record that open second-growth forests of oak and hard pine in southern New Jersey intercepted 13 percent of the summer's rainfall; and jack pine and hardwood-hemlock stands in Wisconsin, 22 and 19 percent, respectively, of the spring and fall precipitation. The Wisconsin hardwoods when in leaf intercepted 25 percent, as against 16 percent after the leaves fell.

Intensive studies of interception of precipitation by tree canopies by the Appalachian Forest Experiment Station has shown that in the case of significant rains of 0.20 inch or more, the amount of precipitation intercepted by the crown canopies may be from 1 percent to as much as 33 percent of the total precipitation. The controlling factors are composition, age, and condition of the stand, and the season of the

[3] Blaney, H. F. Discussion of Forest and Streamflow. Proc. Amer. Soc. Civil Eng., Dec. 1932.

[4] Duley, F. F., and Miller, M. F. Erosion and Surface Run-off Under Different Soil Conditions. Mo. Agr. Exp. Sta. Research Bul. No. 63, 1923.

[5] King, W. R. Surface Waters of Tennessee. Div. of Geol. Dept. of Educ. Bul. 40, 1931.

year. In the case of 25-year-old pine stands, it has been shown that from 1 to 5 percent of the total precipitation reaches the ground by running down the stems of the trees.

Interception of snow by the crowns of ponderosa pines at about 4,500 feet elevation in Idaho, was studied by the Forest Service during 1931–32. In a good stand of virgin timber with an understory of young trees, C. A. Connaughton found that up to the time of maximum storage 27 percent of the winter's snow had been intercepted; in similar mature timber without an understory it was 22 percent; and in a somewhat open stand of ponderosa and lodgepole pine, 20 to 30 feet tall, 8 percent. Studies by Church,[6] Jaenicke and Foerster,[7] and Griffin,[8] however, indicate that snow interception is considerably less in evergreen forest types elsewhere in the West.

Retardation of Snow Melt

Although MacKinney [9] found that light snows melted more rapidly on litter than on mineral soil under a pine plantation in Connecticut, in regions of heavy snow a forest cover retards melting in the spring, thereby materially lessening destructive surface run-off and promoting percolation of the melted snow into the ground. This is due in part to shading of the ground, but mostly to reduction in wind movement; Connaughton found the wind movement during the period of rapid snow melt in Idaho to be more than nine times as great in the open as in the heavy stand of mature ponderosa pine with an almost continuous understory of advance reproduction. Even in the open ponderosa pine forest in which Jaenicke and Foerster worked the wind movement was less than half that in the open.

The following information on retardation of snow melt was obtained in the snow studies just cited. In Idaho the snow cover disappeared in the forest from 3 to 10 days later than in the open; at least 10 days later in Nevada; "several weeks" later in Arizona, the snow occurring, however, merely as drifts in the timber; and from 1 to 5 weeks later in Washington. Ashe [10] reported that 20 inches of snow falling at an elevation of 600 feet in Maryland during March 1906 was 9 days longer in melting beneath a cover of Virginia pine than in the open, and also longer though by a smaller interval beneath an oak forest than in the open.

In the New England floods of March 1936, the heavy rainfall fell on deep snow. The rain was aided by warm winds which hastened the snow melt. Comments of many observers are to the effect that in the open fields, snow melted very rapidly and the run-off from the melted snow was greater because of the frozen soil below. In the woods, snow melt was delayed because the temperature of the air inside the forest averaged lower than that outside, the snow was protected in part from the rain, and sheltered from the warm wind. Further, the soil in the forest was free of frost whereas that of the open field was not.

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[6] Church, J. E., Jr. The Conservation of Snow. Its Dependence on Forests and Mountains. Scientific American Supplement, Sept. 7, 1912.

[7] Jaenicke, A. J., and Foerster, M. H. The Influence of Western Yellow Pine Forest on the Accumulation and Melting of Snow. Mo. Weather Rev., Mar. 1915.

[8] Griffin, A. A. Influence of Forests Upon the Melting of Snow in the Cascade Range. Mo. Weather Rev., July, 1918.

[9] MacKinney, A. L. Effects of Forest Litter on Soil Temperature and Soil Freezing in Autumn and Winter. Ecology, July, 1929.

[10] Ashe, W. W. Relation of Soils and Forest Cover to Quality and Quantity of Surface Water in the Potomac Basin. U. S. Geol. Sur Water Supply Paper No. 192. 1907.

At the Arnot Soil Conservation Experiment Station in Schuyler County, N. Y., the snow in a beech-maple forest was 12 inches deep on March 25, 1936, while there was no snow at all in the open fields. This was after the destructive flood period of March 17 to 24.

The city watershed of Little Falls, N. Y., has been partly reforested. Observations in these plantations by Ray F. Bower of the New York State College of Forestry and R. D. Austin, city engineer of Little Falls,[11] have revealed that over a period of 10 years, the snow cover under the trees did not entirely disappear for from 10 days to 2 weeks following the disappearance of snow in the open fields.

The snow cover prevalent in the forest during the winter prevents the ground from freezing. At the Arnot experiment station the ground in the forests did not freeze during the severe winter of 1935–36, while that in open fields at a depth of 12 inches remained frozen through March 25. During the period March 10 to 19, 1936, the precipitation was 6.4 inches. On the open fields, which had a light snow cover at the beginning of the period, 7.9 inches of run-off occurred; on the forest plots nearby on the same soil type the run-off was less than one-tenth of an inch.

In an address before the National Rivers and Harbors Congress in Washington, D. C., on April 27, 1936, the Secretary of Agriculture told of personal observations made during the floods of March 1936 in the upper reaches of the Susquehanna drainage. Plots had been established by members of the Department from which all run-off and eroded material could be caught and measured. From forested land, where the litter had prevented soil freezing and maintained its porosity, none of the 5-inch rainfall, which extended over several days, was lost by surface run-off. In contrast, the soil of open fields under different methods of cropping was solidly frozen at the beginning of the storm and as a result fully 60 percent, or 3 inches, of the rain ran off the surface immediately.

Reduction of Evaporation From the Soil

In addition to intercepting precipitation and retarding snow melt, the crowns and trunks of trees greatly reduce the rate of evaporation from the soil, just as they have been seen to lessen evaporation or sublimation of snow. In regions of low rainfall, where the forest is open and litter is not continuous or deep on the forest floor, reduction in evaporation from the soil is very much to be desired. Lowdermilk found, in an analysis of factors affecting the yield of water from chaparral watersheds in southern California, in 1930, that if all rain in southern California were to occur as 0.5-inch storms 1 week apart evaporation would account for practically the total supply of meteoric waters. Although half an inch of rain may penetrate the soils of this region to a depth of about 8 inches, when the surface is dried by sun and wind, the moisture is drawn up by capillary action and is evaporated. Burr [12] also found on cultivated ground in Nebraska that a half-inch rain was of no storage value unless it fell on a surface already moist.

Fortunately, all the rain does not occur in California, Nebraska, or anywhere else in the United States in small storms at weekly

[11] Ithaca Journal, Apr. 30, 1936.

[12] Burr, W. W. The Storage and Use of Soil Moisture. Nebraska Agri. Exp. Sta. Research Bul. no. 5. 1914.

intervals, and evaporation from the soil is universally influenced by a forest cover which not only shades the ground but greatly reduced wind movement. In Arizona, according to Pearson,[13] summer evaporation a few feet above the ground within a forest of ponderosa pine may be only 70 percent of the evaporation in the open. G. M. Jemison found that during July and August 1931, evaporation beneath a dense virgin forest of western white pine and hemlock in Idaho was only 22 percent of that in an area clear-cut and burned, and in a similar stand from which about 65 percent of the cover had been removed it was only 47 percent. Bode [14] states that in a heavy oak stand in Iowa summer evaporation was 47 percent and in a reproducing cut-over area 74 percent of that in the open. O. M. Wood found that evaporation during one spring in a rather open, short-bodied stand of mature pine and oak in southern New Jersey was only 65 percent of that in the open.

It is impossible to state what effect these very substantial reductions in evaporation rate within the forest have upon soil moisture. There are almost no American data on seasonal evaporation from a bare soil, and they would not apply to the normally litter-covered soil of a forest. European evidence, as quoted by Zon,[15] shows wide variations, but indicate that evaporation from bare soil in the open, under average conditions, amounts to about 50 percent of precipitation; and that a forest, even without leaf litter, may reduce this to 15 to 25 percent.

CONSUMPTION OF WATER BY FOREST VEGETATION

The water which all plants rooted in the soil withdraw from it in maintaining growth and life is transpired, or given out into the air, chiefly from the leaves. It is very difficult to measure accurately the transpiration from a single tree beyond the seedling stage, and infinitely more so to measure the transpiration from a forest. Blaney et al.[16] employed observations of stream flow to determine the water evaporated from the soil or consumed by canyon-bottom vegetation—willows, tules, and kindred moist land growths—in southern California.

The evapo-transportation losses from Temescal Canyon during only 30 spring days they found to equal 12.9 inches of rainfall. The same author [17] estimated from stream-flow measurements in Coldwater Canyon that the transpiration losses from "alders, sycamores, bay, oak, and herbaceous growth" during the 6-month summer season of 1931 was 45 inches per acre. Evaporation was judged to be small as the water in the canyon bed is constantly cooler than the air. Inasmuch as the precipitation for the entire year is normally only about 30 inches, it is fortunate that the area of canyon-bottom vegetation is very small, and that the loss per acre of entire watershed is only 0.10 inch per mile of canyon. The transpiration

[13] Pearson, G. A. Forest types in the Southwest as Determined by Climate and Soil. U. S. D. A. Tech. Bul. no. 247. 1931.

[14] Bode, I. T. Relation of the Smaller Forests Area in Non-forested Regions to Evaporation and Movement of Soil Water. Proc. Iowa Acad. Sciences. 1920.

[15] Zon, R. Forests and Water in the Light of Scientific Investigations. Final report, Nat. Waterways Com., Sen. Doc. no. 469, 62d Cong., 2d sess., 1912.

[16] Blaney, H. F., Taylor, C. A., and Young, A. A. Rainfall Penetration and Consumptive Use of Water in the Santa Ana River Valley and Coastal Plain. Calif. State Bul. No. 33. (Calif. Dept. Public Works, Div. Water Resources, in co-op. U. S. Dept. Agr., Bu. Agri. Engineering.) 1930.

[17] Blaney, H. F., Discussion of Forests and Stream Flow. Proc. American Soc. of Civil Eng., December 1932.

losses just described are probably at or near the maximum for any forest type in the United States, and fully warrant the expedient, already adopted by such cities as San Bernardino, of piping water out of the stream channel before it can be consumed by the canyon-bottom forest. That the forest cover of the slopes and ridges in this region does not begin to make the same demands on soil moisture is very clear from its dwarfed development.

Data on transpiration rates for other American forest types are entirely lacking and these rates may only be inferred from general knowledge. Many of the statements widely quoted as to the amount of water used by trees and other natural vegetation have been based on European data. These data, taken on very small potted plants or on twigs and small branches cut from trees, cannot be applied universally to large trees grown under forest conditions, and should not be applied to American species or to American conditions.

Interception of precipitation, evaporation from the soil, and transpiration account for a very large part of the difference between the total precipitation over a watershed and the flow of the stream draining it. These differences have been earlier described for various parts of the country. Transpiration probably fully equals the other two factors combined in the hardwood forests of the humid eastern United States.

Influence of Forest Litter

Probably more important than any of the previously mentioned influences of the forest on run-off and stream flow is that exerted by litter. Forest litter is the layer of fallen leaves or needles, of dead branches, down trunks, and other vegetable remains, which in varying depth is found under the crowns of trees and brush species in every Temperate Zone forest. Through the gradual processes of decay and chemical change, and through the agency of animals which burrow into, trample, or otherwise disturb the surface of the ground, this litter is disintegrated into humus. Percolating water then carries the fine particles of humus into the soil where they are further broken down into nitrogenous products by bacteria and other organisms.

Effect of Organic Matter

Forest litter exerts its influence in several ways. First and most important it contributes to the humus content of the soil. It is an axiom in agriculture that humus, or organic matter, makes a heavy soil lighter, and a light soil heavier, by causing the soil particles to form "crumbs." A crumb structure gives the maximum room for air and water, both vital to plant growth.

The addition of humus to the soil also tends to induce a movement of soil particles. This is accomplished in part by swelling and shrinking, and by expansion during times of frost. Such movement develops lines of weakness along which the soil shears when subject to strain and stress.

Studies by the Appalachian Forest Experiment Station have indicated that organic matter acts in still another manner to influence soil structure especially under forest cover. When water containing organic matter, either water soluble or in colloidal suspension, penetrates the soil, it carries the organic matter with it. As the water

evaporates or attains a film structure of near hygroscopic thickness, organic matter comes out of solution or suspension and is deposited on the surfaces of soil grains and granules. For a while, after decomposition, the organic matter is somewhat sticky and tends to hold soil particles together. After exposure to the air for some time, some of this organic matter is carbonized, loses its adhesiveness, and becomes highly resistant to decomposition processes. Groups of soil particles thus surrounded tend to become somewhat stabilized, and the granules of soil particles thus "protected" tend to maintain their identities. Accordingly, when the soil has been broken up into granules due to strains and stresses within the soil, and becomes protected with a thin film of organic matter, it assumes a crumb or granular structure.

In forests the soil receives a new supply of soluble organic matter each year which is sufficient to maintain fungous and bacterial growths to various extents. Fungus mycelia grow downward along the cracks in the soil and thus increase the intensity of the lines of cleavage. Such growths may take place to a depth of several feet. Fungous growth also attacks the organic matter deposited in the surface soil in interstices and around soil particles, etc., and gradually "insulates" the particles from each other with mycelia. In many instances mycelial growth becomes so dense and tenacious that it will hold a large amount of soil together in a clump not easily broken apart. As the mycelia die and disintegrate, spaces are left, so that in time a relatively large amount of pore space is formed. Thus, a forest soil becomes porous, well aerated and capable of absorbing water readily. Dr. H. A. Morgan of the Tennessee Valley Authority has stated that "100 pounds of sand holds 25 pounds of water; 100 pounds of clay holds 50 pounds; but that 100 pounds of humus holds 200 pounds of water."

How powerful an effect organic matter, although an unimportant fraction by weight in most soils, has on the water-holding capacity of the soil is illustrated by analysis in table 1, made by George Stewart of a granitic sand supporting ponderosa pine in Idaho. About 200 samples of the soil were taken to a depth of 4 inches from openings, some large and some small, in a virgin stand. The condition of the vegetation refers to its value primarily as forage, and the deterioration is the result of grazing.

TABLE 1.—*Analysis of granitic sand soil under a ponderosa pine stand in Idaho*

Condition of vegetation	Organic matter [1]	Water-holding capacity [1]
	Percent	*Percent*
Good (nearly original condition)	10.5	81
Intermediate (considerable deterioration)	4.8	55
Poor (bad deterioration, soil usually gullied)	2.4	44

[1] In percentage of dry weight of soil.

The ability of this soil to absorb water was nearly halved by its loss of a very small quantity of organic matter. Inasmuch as the soil of any watershed is the great underground reservoir replenished from time to time by precipitation, but at all times draining into the streams, its absorptive capacity is the great factor in sustained stream flow. Humus and the decaying roots of plants enormously increase this capacity.

EFFECT ON SOIL LIFE

This humus in the soil also provides for a vast population of soil life. In forests of the Appalachian region, Dr. A. P. Jacot has determined that there are up to 10,000 individual microarthropods (minute animals such as spiders, springtails, centipedes, etc.) per square foot of forest litter. These small creatures which feed upon the litter and other organic material, aid greatly in maintaining the looseness of the soil and in keeping the minute channels open and receptive to water.

In addition to the activities of the smaller fauna of the forest floor, must be mentioned the work of the larger animal life, such as worms, crustacea, and insects. During the 1936 emergence of the 17-year cicada, in Rock Creek Park, in Washington, D. C., as many as nine emergence holes per square foot were counted in a dense oak forest. These openings, some of which had a diameter of up to almost one-half inch and averaged five-sixteenths inch, extended downward many inches and in a few instances down to a depth of over 2 feet. While it is obvious that such openings provide means by which water can soak away rapidly to the lower soil levels, these larger openings do not begin to carry the quantity of water that is carried downward by the myriads of smaller soil pores and openings.

WATER PERCOLATION

Another major influence of forest litter is its promotion of water percolation. If a soil is extremely shallow, or if precipitation is unable to percolate into it rapidly, run-off must take place over the surface from any but the lighest storms. If rain falls upon bare soil it becomes muddied and carries fine material in suspension downward into the minute interstices between the soil particles. How promptly and completely muddy water will plug these pores and slow the rate of percolation has been demonstrated by Lowdermilk.[18] After establishing, over a period consisting of parts of 7 days, the rate at which clear water percolated through columns of soil, he introduced sediment of less than 2 percent by weight into the water; within 6 hours the rate of percolation fell to 10 percent of what it had been. Moreover, the effect was permanent, as a return to the use of clear water did not restore the original rate. A good forest litter keeps the rain from becoming muddied when it hits the earth and so decreases run-off; in the absence of litter, surface run-off is enormously increased. When Lowdermilk applied artificial rain, at an average rate of 1 inch an hour, for several periods of one-half to 8 hours, to sloping tanks filled with typical California soils, he found that the surface run-off was from 3 to 16 times as great from bare soils from which the litter was burned as from those on which a litter cover was present.

The effectiveness of forest litter in promoting infiltration into the soil is further demonstrated by an experiment performed in southern Mississippi. A plot representative of fields from which erosion and run-off were excessive was covered with forest litter. Athough the plot had a 10-percent gradient and an extremely compact and unabsorptive soil, the percentage of the annual precipitation lost by surface run-off was reduced to one-half and soil losses to one eighty-eighth of the values for bare soil. Even in heavy rains ranging from

[18] Lowdermilk, W. C., Influence of Forest Litter on Run-off, Percolation, and Erosion. Jour. Forestry, April 1930.

2.2 to 6.3 inches the litter-covered soil absorbed from 32 to 88 percent more rainfall than exposed soil.

In the southern Appalachian Mountains a rain which attained a maximum intensity of 0.56 inch in 20 minutes caused 160 times as much run-off from a plot which had the litter removed by raking as from one with undisturbed litter.

The superior physical condition and consequent permeability of forest soils has been demonstrated for Ohio Valley conditions by Auten.[19] Samples of the upper 9 inches of soil under several old-growth stands in oak-hickory and other hardwood types were found to be 13 percent lighter at oven dryness than equal volumes of soil from adjacent cultivated fields and a few pastures—indicating more pore space and better tilth. Although this difference in weight was later found to be confined to the upper 6 inches, the forest soil was still distinctly the more pervious to moisture at a depth of 8 inches. At a 3-inch depth 14 times as much water was absorbed per minute by the forest as the field soil; and at a 1-inch depth, over 50 times as much.

Favorable soil porosity returns to old fields after forest planting. At 1-inch depth, the average rate of absorption in a 17-year-old plantation was 107 cubic centimeters per minute, as contrasted with only 8 cubic centimeters in an open adjacent field.

During the summer of 1934 a series of tests was made of the absorptive capacity of cherty and sandy soils in northern Arkansas and on yellow silt loam soils in southern Illinois. Both areas are in the unglaciated region of the Ozark highland which extends from southern Illinois through southern Missouri and northern Arkansas. The Arkansas area is representative of the Ozark region of Missouri and Arkansas, while the Illinois area is typical of the silt-loam areas of southern Illinois, southern Indiana, and southeastern Ohio.

TABLE 2.—*Rate of water absorption in cubic centimeters per second, per square foot of soil*

Soil type	Site conditions	Volumes of water absorbed per second [1]			
		First liter	Second liter	Third liter	Fourth liter
		Cc	*Cc*	*Cc*	*Cc*
Yellow silt loam, Illinois	Undisturbed oak woods	21.83	23.36	22.78	21.23
	Burned oak woods	7.60	4.63	3.40	2.64
	Open pasture	2.52	1.34	1.01	.86
Cherty silt loam, Arkansas	Undisturbed oak woods	55.87	44.87	38.76	32.05
	Burned oak woods	14.25	9.78	6.12	5.10
	Open pasture	17.73	10.47	6.16	4.74
	Old-field pine woods	53.19	35.21	21.10	14.71
	Open pasture	12.32	7.66	8.04	6.37
Sandy soil, Arkansas	Undisturbed oak woods	64.10	46.08	40.00	30.50
	Open pasture	24.33	16.84	14.35	12.92

[1] 4 successive applications of water were made.

The data given in table 2 show that in the Illinois silt-loam soils there is a great decrease in the water-absorptive capacities of severely burned forest and pastured soils compared with the undisturbed woods. In the case of the latter, the rate of absorption, for each successive liter of water applied, remained relatively constant

[19] Auten, John T., Porosity and Water Absorption of Forest Soils. Jour. of Agr. Res., June 1, 1933.

throughout the test, whereas in the case of burned woods and pastured soils, the rate of absorption diminished with each application. For both burned woods and pastured soils, the rate of absorption of the fourth liter of water was only 35 percent that of the first.

This decrease in water absorption can be explained by the compaction of bare surface soil which occurs during rainfall and by the sealing of the soil pores. The porosity of the forest soil, which is preserved by the protective covering of leaf litter, is lost when the litter is destroyed by fire or by livestock grazing.

Because of its stony structure, the Ozark soil absorbed water more rapidly than did the Illinois silt loam, yet the soils of the repeatedly burned woods and the pastures lost their porosity to a remarkable degree. The rate of absorption of the undisturbed forest soils decreased somewhat with each successive application of water, but not nearly as rapidly as it did in the soils of the burned woods and the pastures. When the fourth liter of water was applied, the rate of absorption in the undisturbed woods was 68 percent of the first application; whereas in the case of the burned woods and pasture, it had dropped to 36 percent and 27 percent, respectively.

Although the undisturbed woods on sand and on cherty silt loam have similar rates of absorption, the rate for the pasture with sandy soil is greater than that for the pasture on the cherty soil. The rate for the fourth application of water on the sand pasture is 2.72 times as great as that on cherty silt loam pasture. This indicates that sandy soil loses less porosity, relatively, than does a silt loam. It must not be overlooked, however, that the absorption rate for woods on sand decreased about two-thirds when the land was cleared and pastured. It is evident that even on sand there is a significant loss of water absorption brought about by exposure and pasturing.

Tests on an old-field pine site show that porosity is regained when a cleared area is reforested. In this particular case the results were less striking, no doubt, because of the fact that prior to 1929 the pine area had been repeatedly burned.

The favorable conditions of the forest soil reflected in these results is not due to the litter and animal life in the soil alone, for the roots of the trees, shrubs, and lesser vegetation ramify through the soil in an amazingly intricate network. Near the surface this network is particularly closely woven and below 2 feet is somewhat less so. While the roots are alive, their growing tips force a way into minute cracks in the soil particles, expand and enlarge the opening, or break the particles into still finer grains. As the roots get larger the process of growth and the action of frost tend to open channels around the roots down which water may flow. When the roots die, as happens each year with the herbaceous vegetation and at longer intervals with the shrubs and trees, they quickly decay, leaving direct cylindrical channels which become as effective as pipes in leading water into the lower soil.

An effect similar to that of litter cover in aiding percolation and in lessening the proportion of surface run-off is produced by low, permanent vegetation. Duley and Miller (op. cit.) state that whereas only 11.5 percent of 6 years' rainfall ran off over a sloping surface protected by a permanent grass sod, kept clipped, 49 percent ran off bare soil. Even where tilth of the bare soil was maintained by annual cultivation, nearly 30 percent of the precipitation was carried off over the surface.

ABSORPTION OF WATER

Other but sometimes important effects of litter upon run-off are produced by its absorption of moisture. Investigations by the Forest Service and other agencies [20] have shown that litter can absorb water equal to many times its own dry weight.

A number of investigations have determined the water-holding capacity of litter from typical forests in various parts of the country. In the Northeast the water-holding capacity of the litter ranges from 300 to 900 percent of the dry weight of the litter, the highest values being obtained in the spruce and in the northern hardwood forests. Freshly fallen pine litter in the Lake States absorbs water to 156 percent of its dry weight. In the Central States region the absorptive capacity of the scanty hardwood litter averages about 360 percent. In the southern hardwood forest it ranges up to 400 percent, and in the southern pines from 150 to 350 percent, the lowest values being for freshly dropped litter.

In the Appalachian Mountains the water-absorptive capacity of the litter ranges from 300 to 535 percent. The average for hardwood stands was determined to be approximately 458 percent and for conifers 344 percent. For certain material, such as the moss commonly found under laurel, values ranged as high as 890 percent; for decayed logs they ranged from 343 to 537 percent. On account of the fact that ground fires are common throughout the Appalachian region, these represent only the capacity of 1 or 2 years' accumulation, or a litter depth of rarely more than 2 inches.

The absorptive capacity of forest litter varies, in terms of rainfall equivalent, from 0.10 to 0.93 inch. The poorest values were from the litter of a hardwood forest where cutting had been quite heavy and where the stand was open. The best results were obtained in relatively dense forests of spruce, birch, cedar, and poplar, and where the forest formed a complete canopy.

In peat deposits, such as are characteristic particularly of the spruce forests of the Lake States and the higher portions of the Appalachian Mountains in the Ohio River drainage, the amount of water absorbed may easily be several inches, this amount being dependent upon the depth of the deposit. The full absorptive value of these deposits, however, is not often available because peat is seldom reduced to complete air dryness.

The influence exerted by litter upon the water situation of a large region can be illustrated in part by the data obtained for the Appalachian Mountains. There is every reason to believe that the values here given would be too low if applied to the whole hardwood-forest region, but they are indicative. In this study it was determined that the absorptive effect of hardwood litter is greatest on the middle and upper north slopes and lowest on the upper south slopes in the Appalachian region. On the lower slopes, according to Dr. C. R. Hursh of the Appalachian Forest Experiment Station, there is but little difference in the absorptive capacity of the litter on different aspects. In the coves, decomposition is apparently so rapid that the accumulation of litter is less rapid than on the dry slopes. However, assuming similar litter conditions on south and west slopes and also

[20] Relation of Forestry to the Control of Floods in the Mississippi Valley, H. Doc. No. 573, 70th Cong. 2d sess., 1929.

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on north and east slopes, the following may be considered the average of equivalent precipitation held in the Appalachian Mountains litter during times of heavy rain:

Location	Area (percent)	Possible absorption of water by litter (inches of rainfall)
Upper south and west slopes	20	0.033
Lower south and west slopes	20	.190
Upper north and east slopes	20	.241
Lower north and east slopes	20	.186
Cove bottom and lower cove slopes	20	.194
Average for region		.169

Investigations in Ohio by the Central States Forest Experiment Station indicate that comparatively young plantations have considerable influence upon flood flow and erosion. It was found that forest plantations ranging in age from 12 to 20 years had developed a uniform litter cover which was rapidly increasing in depth and in value. The absorptive capacity of the forest floor was determined as ranging between 100 and 250 percent of the dry weight of the material, indicating the possibility of an absorption of more than 0.20 inch of rainfall.

The Red Plains Experiment Station near Guthrie, Okla., found the litter on a post-oak area to have a water-absorption capacity of 16.7 tons per acre.

OTHER EFFECTS

American data on the effect of a litter cover on evaporation from forest soils are singularly lacking, but European comparisons, quoted by Zon (op. cit.) of forests with and without litter, indicates that this natural forest mulch may reduce evaporation by 40 to 60 percent.

A litter cover materially retards both the rate and depth of freezing of the soil beneath. MacKinney (op. cit.) found that under a 2-inch litter in a Connecticut plantation of Norway and white pines frost in 1926–27 was a month later in penetrating the soil at all, and final penetration only 60 percent as deep, as where the litter had been removed.

The character of the frozen soil was influenced markedly by the litter. The soil of the bare area froze solidly, and the air spaces were practically filled with ice. On the other hand, the frozen soil beneath the litter cover was porous and loose, at no time being frozen too hard to allow the insertion of a shovel. During winter rains and thaws the water soaked into the soil of the litter-covered plot and percolated to lower depths. On the bare plot the water ran off at such times, due to the nonporous character of the frozen soil.

Summary of Influences

Because forest that conserves snow and reduces evaporation of soil moisture must at the same time interrupt precipitation and transpire water drawn from the soil, its final effect on run-off can only be determined by the balance between these opposing influences. Whether this net effect is beneficial or harmful in any particular region is

probably determined in part by the total amount of precipitation, but chiefly by the occurrence of precipitation as snow or rain, its distribution throughout the year or during only a part of it, and its arrival in light or heavy storms. American research to date, backed by a large body of observational evidence from all parts of the United States, justifies a strong belief that the forests of the country practically always benefit stream flow. A possible exception is the canyon-bottom vegetation of the drier regions, earlier described; even this may prove to have a net favorable effect in the checking of erosion. There can be no doubt at all that the net effect of forest litter, although it intercepts some precipitation and returns it into the air by evaporation, is extremely beneficial, since it reduces surface run-off and increases the water-storage capacity of the soil by increasing percolation at the same time that it shelters the soil moisture from evaporation.

From a careful consideration of each main region, it appears fairly evident that the climax forest—that type of forest which is best adapted to the climate and soil, and which nature, in the absence of fires, human interference, or epidemic of tree-killing insects and diseases, always tends to produce—was admirably adapted to promoting stream-flow conditions favorable to mankind. For example, the dense hardwood and hemlock forests of the southern Appalachian Mountains, where annual rainfall is heavy and floods result from a succession of storms rather than from a single very heavy storm, appear to constitute just the forest type to intercept the maximum of precipitation in the tree crowns and litter, and to reduce the flood crests by keeping part of the rain or melted snow from ever reaching the soil. Were such a forest capable of developing in southern California, where the comparatively light precipitation supplies a vital human need in the rich valleys, its draft on available moisture would be extremely serious. But the forest actually present on the hillsides is a dwarfed one, not transpiring appreciably at the season of heaviest rainfall, but producing a leaf litter having a profoundly favorable effect on percolation and water storage.

The natural climax forest of a region, although a valuable guide to what constitutes the best form and composition for a forest managed chiefly for its influence on run-off and stream flow, is not beyond improvement. It is entirely possible that by appropriate management, man can produce a forest with an even greater beneficial influence than the original.

Furthermore, there are undoubtedly many other ways by which forest lands can be made to aid in flood control. Measures, such as have been used on agricultural lands, can also be used to some extent on forest lands. For example, the terrace system widely used in India famine relief and by the Italian integrated land development program, has already been applied to some forest lands. In the Wasatch Mountains, serious floods and destructive erosion from denuded lands have been corrected in part by a series of terraces which now have gone through two serious flood seasons with great success. On the terraced half of one watershed, no erosion or run-off occurred while on the unterraced area, flood waters capable of moving boulders 9 feet in diameter developed. Thus forests can be augmented by such measures as terracing, ditching, water spreading, check dams, stream rectification, and in many other ways.

HOW FOREST COVER INFLUENCES EROSION

Erosion, the removal of soil by water and wind, is taking place on all land areas. Where this occurs on land that has not been disturbed by man and is subject to no extraordinary climatic conditions the process may be termed "normal erosion." The intensity of normal erosion is determined chiefly by topography, geology, soils, climate (especially precipitation), and vegetative cover. Only rarely does it assume an intensity that involves serious damage to soil or to water flow or storage. In humid regions completely clothed with vegetation, as in a dense forest, natural processes are forming soil as rapidly as it is eroded and actual net loss, if any, is imperceptible. Surface run-off is ordinarily negligible, and consequently what erosion there may be is limited to light or dissolved particles of organic matter and practically no mineral soil is removed. Where the forest and other vegetative cover is definitely scant, as under semiarid conditions, there is still enough vegetation or debris to catch eroding soil and litter on slopes, retard run-off, and cause deposition of much of the eroded material already in motion. Even a light vegetative covering, if undisturbed, is sufficient to hold normal erosion to a negligible quantity. Only where the soil is unstable and easily erosible, as in the Badlands of the Dakotas, is normal erosion sufficiently rapid as to be perceptible.

On the other hand, when natural conditions are disturbed and nature's balance is upset by a reduction in the forest cover as a result of fire, logging, or overgrazing, or by marked changes in climatic conditions or other major causes, erosion in excess of the normal is liable to occur. Furthermore, abnormal erosion, where it does occur, is an accelerating process. Its least conspicuous form is as sheet erosion, recognizable in the exposure of root crowns and roots of plants, in the lowered productivity of the site, in the accumulation of soil on slopes immediately above obstructions, and in the final disappearance of the mellow black surface soil. As the mellow surface soil is washed away, a more compact subsurface soil is generally exposed, less capable of absorbing rainfall and less resistant to erosion. Furthermore, decreased productivity may render it incapable of supporting as dense a stand of vegetation as formerly. There is thus less obstruction to run-off, less binding power in the soil, and less possibility of rebuilding the organic content. As sheet erosion becomes advanced the more rapid surface run-off concentrates and tends to cut small gullies. After hard rains on soils inadequately protected by vegetation the entire area may be cut by lines from the size of a pencil to gullies several feet deep. The smaller lines may be readily obliterated by creep of soil as it dries, but their original presence indicates a rapid soil wastage.

Finally, abnormal erosion assumes its most spectacular form as deep gullies on slopes and large straight-sided channels cut through flood plains. Its final effects are heavily soil-laden streams, especially when in flood; silted channels and reservoirs; mud and rock flows from mountain stream courses; and deposits of inert sands and gravels on fertile bottom lands.

The control of erosion through retarding run-off is largely a function of the vegetative cover. This cover is responsible for improvement of soil structure, protection of the surface soil from beating rains,

and, by intercepting run-off, reduction of the velocity and carrying power of the surface water. Lowdermilk has pointed out in his studies under controlled conditions that the run-off from soil surfaces protected by a litter cover alone was nearly clear. A summary of Lowdermilk's findings in table 3 shows strikingly the value of forest litter in reducing erosion on three important soil types. The weights of soil eroded from these plots, all of which had been litter covered for a year before half of them were burned bare, indicate that, on the average, removing the litter caused, respectively, 73, 160, and 1,196 times as much sediment to be eroded as was carried off from the protected soils. Studies in Arizona by C. K. Cooperrider, of the Southwestern Forest and Range Experiment Station, show that a vigorous herbaceous and shrub understory in the woodland type exerts a somewhat similar influence.

TABLE 3.—*Weights of soil eroded from plots protected by litter cover and plots burned bare on slopes of equal gradient and soils of three important types, under equal quantity and duration of artificial rainfall* [1]

Time of run	Average total rainfall	Sandy clay loam		Fine sandy loam		Clay loam	
		Litter covered	Bare	Litter covered	Bare	Litter covered	Bare
Hours:	*Inches*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
½	7.86	0.05	18.6	2.00	234.0	0.51	285.4
1	15.44	.40	40.6	1.70	646.8	.60	593.7
1½	21.45	2.00	38.2	.95	28.1	.44	1,279.4
2	20.17	.35	89.6	.59	235.6	2.02	1,238.2
4	43.19	.45	35.4	2.48	19.0	.75	404.1
8	77.31	.50	48.6	1.07	235.6	.62	2,082.2
Average		.62	45.2	1.46	233.2	.82	980.5

[1] 10 runs made for each combination of time and condition.

THE RELATION OF EROSION TO FLOOD RUN-OFF

Accelerated erosion tends to increase frequency and height of floods through increased volume and flashiness of run-off, and decreased discharge capacity of alluvial channels. The volume of run-off is increased chiefly by lowered permeability of eroded soils and lessened time of possible percolation.

The flashiness of run-off from margin to center of drainage basins is increased by accelerated erosion, chiefly by development of gully streams. These extend depressions and abnormal slopes toward the divides, thus providing for the immediate collection and torrential flow of surface waters from peripheral uplands, into the main valleys. Peripheral rainfall thus tends to overtake and join with waters falling closer in, to congest major valleys with flood waves of abnormal height and abrupt frontal slope. Abnormally rapid downstream propagation and junction of such waves, from confluent headwater basins, are responsible for abnormal floods in succeeding major valleys.

The water discharge capacity of alluvial channels leading out of regions of accelerated erosion is decreased by accumulations of sediment, due to overloading of the stream by abnormal soil wastes from headwater areas. Flood discharge is thus more largely diverted to over-bank area, where velocities are lower, and flood levels of given discharges are correspondingly elevated.

Accelerated erosion also tends generally to increase surface run-off at the expense of natural replenishment of underground waters. This must tend in time to lower the water table, both locally and generally, in regions of notably accelerated erosion. There has been increasing complaints of a gradual lowering of the water table in many sections of the United States dependent upon underground water supplies. This reduction in ground water supply apparently is keeping pace with the acceleration of erosion on agricultural lands. As the reduction has continued through a wide variety of rainfall periods, it indicates the possibility, if not the probability, that excessive surface or flood run-off, largely due to man-induced erosion, is at least a major contributing factor to waning underground water supply.

Accelerated erosion in mountainous watersheds tends to increase floods and the total yield of water. However, even in regions where water is valuable for irrigation and other uses, the amount of usable water is decreased because the flood flow is so charged with sediment as to be unfit for direct use.

Thus, the result of disturbance of the natural cover of vegetation is increased surface run-off which on denuded lands at least, means increased floods.

The Relation of Erosion to Flood-Control Structures

The erosion of denuded lands not only increases flood heights, and thereby increases flood damage, but also decreases the value, through silting, of man's engineering works designed to control floods. In some places, this silting is proceeding at such a rate as to threaten to destroy proposed down-stream engineering structures within but a few generations (table 4). This silting may fill reservoirs behind dams or it may so fill in the stream channels that levees must be raised higher to take care of floods of the same magnitude. A striking example of such sedimentation is evident on many of the minor tributaries of the Yazoo River in northern Mississippi. Here erosion of the uplands has caused such heavy deposition of sand and gravel in stream channels that the streams no longer flow in their old beds but now flow in new channels cut in former agricultural land. Many of these new channels are several feet above the bed of the original stream.

Of 56 reservoirs examined by the Soil Conservation Service in the southern Piedmont in 1934, 13 major reservoirs with dams averaging 29.8 feet in height were completely filled by eroded material within an average period of 29.4 years. In the West, significant instances of complete filling of reservoirs include the Austin Dam at Austin, Tex., which was nearly filled in 5 years and completely filled in 15, and the Harding Reservoir near Santa Ana, Calif., which filled almost entirely during a single month of heavy rains following a burn in the basin during 1927.

TABLE 4.—*Rate of silting of reservoirs*

Reservoir	Period covered	Years	Annual loss of storage capacity in per-cent	Years re-quired to reduce to average annual draft
Spartanburg, S. C., city reservoir	1926–34	8.00	2.14	36
High Point, N. C., city reservoir	1927–34	7.00	.84	97
Rogers, Tex., city reservoir	1922–34	12.00	1.90	13
Elephant Butte Reservoir, N. Mex	1915–25	10.70	.89	77
Zuni Reservoir, Black Rock, N. Mex	1907–32	25.00	3.62	18
Roosevelt Dam Reservoir, Ariz	1910–25	15.00	.41	124
Elk City, Okla.[1]	1925–35	10.00	4.80	
Old Lake Austin, Austin, Tex.[1]	1893–1900	6.75	6.80	
Waco, Tex.[1]	1930–35	5.00	2.48	35

[1] Information taken from Soil Conservation May 1936.

Differences in rates of silting depend upon a variety of factors from one region to another. In the Southeast the high rate of reservoir silting is the result chiefly of erosion of deep residual soils as influenced by human occupation. In mountainous and other regions where the natural forest cover is practically intact, lower rates of silting occur. At the Greensboro and High Point Reservoirs in North Carolina and the Spartanburg and Appalachee Reservoirs in South Carolina where only about one-half of the drainage area is in forest the rate of silting is high. But at a series of Appalachian Mountain reservoirs—Little River Reservoir near Brevard, N. C., Green River Reservoir near Tuxedo, N. C.; and Burton, Raburn, Nacoochee, and Tallulah Reservoirs on the upper Tugalo River Basin near Tallulah Falls, Ga.—where almost all of the drainage area is in forest—the rate of silting is almost negligible.

In the Southwest high rates of silting are largely the result of overgrazing, which induces extraordinary sheet and gully erosion. At the Elephant Butte and Zuni Reservoirs in New Mexico and the Coolidge and Roosevelt Reservoirs in Arizona, the watersheds are subject to both sheet and wind erosion and to arroyo and gully development and the bad lands type of dissection. In the watershed areas of the Zuni and Roosevelt Reservoirs, sheep grazing is responsible for much of the accelerated erosion.

In the California region higher rates of reservoir silting are the result for the most part of watershed fires. At the Gibralter Reservoir near Santa Barbara, fires have occurred regularly in the watershed basin, and the rate of silting has increased progressively with the extent of the burning. At the Harding Reservoir near Santa Ana, practically all of the basin was burned over in 1926. Prior to the fire the reservoir silted very little After the fire, a series of heavy rains induced severe erosion and the reservoir was practically filled within a month. At the Santiago Creek Reservoir, which is located about 6 miles downstream from the Harding Reservoir, fires have been few and the rate of silting has been very low.

Such rapid silting merely adds greater point to the need for forest cover on all nonagricultural lands above the dams as a correlary protection to flood-control dams. This wholly apart from the beneficial influence of the cover itself on floods and run-off.

CONSEQUENCES OF DISTURBING THE FOREST COVER

Fire

Fire is the most widespread and one of the most destructive disturbances of the forest cover. Even the lightest fire consumes some of the inflammable materials on the ground—the litter in all its forms. The extent of destruction of these materials depends in the main upon their moisture content, and the humidity and other climatic factors at the time of the fire. In many forest types it is a common occurrence for the litter to be entirely consumed by a fire which does not do any spectacular damage to the standing trees. Thus is destroyed the enormously important protective soil covering, a chief factor in the forest's favorable influence on run-off and erosion. A fire which is hot enough to consume most of the litter ordinarily also destroys part of the humus in the top soil, thus damaging its loose, porous, granular structure, and making it less receptive to penetration of rain.

Bennett [21] in reporting on an unpublished finding of S. W. Phillips and I. T. Goddard at the Red Plains erosion experiment station near Guthrie, Okla., in the spring of 1930, states that on two plots in post-oak timber, one on which the forest litter was burned, and the other, immediately alongside, on which the natural ground cover of leaves and twigs was left undisturbed—the run-off was measured during a period of almost continuous rainfall in May. Run-off from the unburned plot was clear and amounted to 250 gallons per acre, but that from the burned plot, having the same soil and slope, was muddy and attained a volume of 27,600 gallons per acre. The excess of run-off from the burned area over that from the unburned area plus the 16.7 tons per acre absorbed by the leaf-litter itself was approximately 90 tons per acre. The absorbed water went to replenish the underground soil water supply while that held by the litter was largely evaporated. From the burned plot an average of 0.15 ton of soil per acre per year was eroded, and from the unburned plot 0.01 ton.

Similar studies in the eastern mountains made by scientists on the staff of the Appalachian forest experiment station show that removal of the litter under an old growth pine-hardwood forest by fire resulted in surface storm flow averaging 10 times as great as that on adjacent unburned control plots with differences as great as 32 times for individual storms.

In spruce forests of the East, particularly at high altitudes, fires have been very destructive. Here the mineral soil is shallow, and in places almost lacking, under a deep duff. Where this covering has been burned, the soil itself is practically destroyed. Studies by the Appalachian forest experiment station on a 1924 burn in West Virginia indicated that spruce and hardwood litter from 12 to 18 inches deep was destroyed. In his report on the southern Appalachian region, which had a large influence in bringing about the purchase of national forests in the eastern United States region, Glenn [22] said of the Blackwater Basin in Virginia:

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[21] Bennett, H. H., Relation of Erosion to Vegetative Changes, pp. 385–415. Scientific Monthly, November 1932.

[22] Glenn, L. C., Denudation and Erosion in the Southern Appalachian Region and the Monongahela Basin. U. S. Geol. Sur., Prof. Paper No. 72., 1911.

All of the Blackwater Basin except its lower part has been thoroughly lumbered and then burned over, so that in many places the bare rocks are exposed and scarcely anything but briers and fire-scald cherries have since been able to take hold. It will be years before a commercial forest can be started and centuries before the magnificent hemlock, spruce, and pine that once covered it can grow again.

In the 20 years since this prediction was written, conditions have not materially changed on large areas, and the Forest Service has been obliged to plant part of the present Federal holdings.

In the chaparral type of California, a type characteristic of watersheds of critical importance to a large population, hot summer fires destroy the entire cover on thousands of acres every year, often leaving several inches of ash on steep slopes completely exposed to erosion. If the fall and winter precipitation comes as mild, well-sustained rains, studies of the California forest experiment station have shown that a good cover of annuals will come in, and that these, together with sprouts from such crowns of shrubs as remain alive, may be sufficient to hold much of the soil in place. However, these rains are more apt to come as semitorrential downpours before an adequate vegetative cover has become reestablished, and then great quantities of soil are washed from the slopes in the rapid unobstructed run-off.

Hoyt and Troxell [23] have compared the run-off of Fish Creek with that of Santa Anita Creek, neighboring watersheds, for the 7-year period from October 1917 to September 1924 when both were covered with forest and chaparral, and then for the 6-year period following a fire in the fall of 1924 which denuded the Fish Creek watershed. In the first year following the fire they found a 231-percent increase in run-off over their estimated normal of 1.07 inches and an increase of 1,700 percent in the maximum daily discharge resulting from the first four storms occurring after the fire. The flood peak, which was ordinarily 2.5 times the maximum daily discharge prior to the fire, increased to 16.2 times on April 4, 1925.

During the second year after the fire Hoyt and Troxell found an increase of 26 percent above the estimated normal in the run-off from Fish Creek and during the 6-year period after the fire an average annual increase of 29 percent. Blaney (op. cit.), however, has attributed this increase to the destruction not of the chaparral, which constitutes 97 percent of the watershed, but of the canyon-bottom forest.

Hoyt and Troxell themselves point out that under normal conditions erosion in the watersheds of Fish Creek and adjacent creeks was negligible, but that samples of water collected from these streams during 4 months immediately after the fire showed a total sand and ash content of 20 to 67 percent by volume and 6 to 40 percent by weight. They state also that in the first year after the fire the large deposit of silt from the burned-over area caused considerable damage to orchards, railroads, and highways adjacent to the mountains.

Cecil,[24] in discussing the usability of water from southern California watersheds, states:

The prime requisite in water production is that the water must be usable. This factor is of greater importance than the quantity produced and is vastly more important than a minor increase in the sustained summer flow. * * * The

[23] Hoyt, W. G., and Troxell, H. C., Forests and Stream Flow, Proc. Amer. Soc. Civil Engin., pp. 1037-1066. Vol. 58, August 1932.

[24] Cecil, G. H. Discussion of "Forests and Streamflow." Proc. Amer. Soc. Civil Eng., December 1932.

replenishment of these underground reservoirs * * * is of paramount importance. For years past, several communities, have spread the floodwaters over the detrital cones by means of lateral ditches, increasing the wetted area and materially increasing percolation over that obtaining under natural conditions. The experience of these companies has proved beyond a doubt that, in order that water may be spread successfully and the maximum of percolation secured, it must be free of suspended matter. It is often necessary, during the first run-off of the season, to bypass to the ocean a varying part of the flood flow. In the case of a watershed that has been run over by fire, the quantity that must be bypassed because of the silt load is many times as great as that under normal conditions.

Reports of the Forest Service indicate that before the 1924 fire on Fish, Sawpit, and Rogers Creeks practically all the run-off of these streams was either used for direct irrigation or went to replenish underground reservoirs as described by Cecil. After the fire, much of the run-off in 1925 was unusable because of erosion debris.

Under the semiarid conditions of southern California it ordinarily takes not less than 5 years for enough vegetation to be reestablished on burned watersheds to serve effectively in handling semitorrential rains. In instances where much of the productive topsoil is washed off from the slopes as a result of hard rains in the first year, it will take considerably longer than 5 years to reestablish a closed canopy for the soil.

In the pine region of the Sierras, a 5-year record of the run-off and erosion from repeatedly burned and comparable unburned plots has shown a yearly run-off from the burned area ranging from 31 to 463 times that from the unburned, and a yearly erosion ranging from 22 to 239 times that from the unburned. The run-off from a plot allowed to revegetate after a single burning exceeded the run-off from an unburned check plot by 31 times the first year, as against 11, 5, 15, and 14, times in the subsequent 4 years; and after carrying off 485 times as much eroded material the first year as the check plot, it carred the second year only 81 times as much. Analysis of the surface soil reveals that the average volume weight from the annually burned plots is 10 percent greater than that of the top soil from the undisturbed plots.

In 1929 a fire burned over a considerable portion of the Camas Creek watershed on the Challis National Forest in Idaho. It was evident in the next year that the fire had materially increased erosion. Extensive dry erosion (i. e., trickling of dry soil down steep slopes) and heavy sheet erosion had occurred. This process, begun immediately after the fire, was still going on in 1936.

Serious erosion was also evident on many of the older fire-swept areas. Such examples may be found around Lookout Mountain on the Idaho National Forest which was burned in 1919 or before, and on Sabe Mountain on the Bitterroot National Forest in Idaho, burned in 1910. The exposed roots of the snags and the elevated clumps of bear grass indicate that some 5 inches of soil has been eroded from the burned-over slopes since the 1910 fire.

A torrential rain on the Challis National Forest in 1932, for example, caused excessive run-off to originate on a 1931 burn, resulting in a heavy deposit of sand and debris in tributaries of Loon Creek, sufficient to destroy all possibility of fishing in the stream at least for a number of years. Run-off, the result of a heavy rain in 1932 on a 1931 burn in Richardson and Mann Creeks on the Idaho National Forest, caused deep gully erosion on the slopes and erosion of the

stream channel to bedrock. The debris that was swept down these creeks into the Salmon River was sufficient to dam the swift-flowing Salmon River to a depth of 20 to 25 feet and a length of 450 feet, and to cause a new rapids to be formed in the river.

A marked effect of fire on stream flow has been evident under somewhat more humid conditions in the northern Rocky Mountains. In 1919 about 18 percent of the Clearwater River drainage, largely timbered, above Kamiah, Idaho, was burned over, but reclothed rapidly with brush and herbaceous vegetation. The Clearwater River gage records of the United States Geological Survey and data of the Weather Bureau for 10 years, 5 before and 5 after the fire, were analyzed by L. F. Watts, of the Northern Rocky Mountain Forest Experiment Station. These indicated a somewhat higher flow, in relation to precipitation, following the fire, but one much less equable. The average date of peak flow of the Clearwater was advanced by 14 days, in contrast with that of the Salmon River, the drainage of which had suffered much less from fire, which was only 2 days earlier. The average flow of the Clearwater on the peak days was 9.5 percent greater after 1919, in spite of the fact that the highest peak of the period occurred in 1917, as a result of exceptional rainfall in April and May. Furthermore, the April to June run-off increased from 66 percent of the total annual flow to 73.5 percent, and the July to September run-off decreased from 13 percent of the yearly flow to 9 percent. In other words, after the fire the spring flood was 11 percent greater than before the fire, and the summer run-off was 32 percent less. April to June flow is, of course, chiefly the result of surface run-off from melting snow, while July to September run-off results almost entirely from the slow drainage of ground water. The fires appeared to have increased the spring flood flow, but largely at the expense of summer flow.

In California a disastrous flood in Los Angeles County on January 1, 1934, caused the loss of 34 lives, focused public attention on the source of floods, and demonstrated the value of forest cover. A special study of this flood was made by the California Forest Experiment Station. The storm which caused the flood extended over a wide belt of foothills and mountains and deposited an average of 12 inches of rain within 2½ days over a 50-mile front. The watershed in which the destructive flood originated— a flood more of mud than of water—comprises 4,000 acres, burned over only a few weeks earlier. Neighboring watersheds subject to the same rainfall but with their forest cover intact yielded clear water which caused no unusual erosion and did no damage. The maximum flood discharge from the burned-over drainage basin reached 1,100 second-feet per squre mile, carrying some 67,000 cubic yards of eroded debris (table 5). The run-off in unburned San Dimas Canyon, a few miles distant, was only 50 second-feet per square mile and carried only 56 cubic yards of eroded material.

TABLE 5.—*Run-off and erosion from burned and unburned watersheds, storm of Dec. 30–31, 1933, and Jan. 1, 1934, Los Angeles County, Calif.*

Watershed	Rainfall for storm in inches	Total area of watershed in square miles	Percentage of total area		Run-off—maximum cubic feet per second per square mile	Erosion—cubic yards per square mile
			Unburned	Burned		
Verdugo	12.56	19.13	67	33	1,000	50,000
Arroyo Seco	12.32	16.24	99.4	[1] 00.6	[2] 58	(3)
San Dimas	10.82	16.85	100.0	0	51	56
Haines	11.26	1.45	68	32	1,000	67,000

[1] Recorded by U. S. Geological Survey. Other records computed from channel measurements.
[2] This area of 58 acres, lightly burned in backfiring during the battle with the main conflagration, was too small to affect appreciably the run-off from this large watershed. Forest officials in the canyon reported that the material which muddied the water of the Arroyo Seco in its lower reaches came directly from the gullying of road slopes of the new Angeles Crest Highway.
[3] No record.

In October 1935 the chaparral cover in Frankish Canyon near San Bernardino, Calif., was destroyed by fire. On January 31 to February 2, 1936, and again on February 11, destructive floods occurred. On February 11 a flood of water 10 feet in depth swept the canyon, while forested San Dimas Creek nearby was not affected.

Logging

Logging in the United States, which includes the removal of other products besides logs, is very variable in the proportion of the trees which it removes and its effect on run-off and erosion. Although a few small areas—mostly farm woodlands—are only culled of a few of the larger or choice trees at any one time, the common commercial practice on the 10 million acres of forest annually cut over is a very close approach to clear cutting. Through a combination of cutting and fire about 850,000 acres of this are devastated each year—that is, left in such condition that they are incapable of producing another commercial crop of timber within a tree generation. The greater part of this area is almost devoid of standing trees, particularly in the softwood forest regions of the South and West, but some of the eastern hardwood land may have a considerable stand—worthless as a source of wood but very satisfactory as a watershed protection.

Logging alone, if neither preceded nor followed by fire, destroys a smaller proportion of the understory of young trees and shrubby species than of the main stand. However, important areas are still logged by high-powered machinery that drags logs over the ground and wipes out the lesser vegetation. It may even so churn the soil as nearly to obliterate the litter.

On a clear-cut area there is no longer appreciable interception of precipitation by tree crowns, and little high shade to retard snow melt or prevent evaporation. There may be, however, some shading of the ground by slash. This, in such conifer types as Douglas fir, western white pine, southern white cedar, or red spruce, may cover practically 100 percent. After a year or two this slash itself may become powder dry, but it continues to exert some beneficial effect on evaporation from the soil.

In many forest types clear-cut areas are very abundantly invaded within a season or two by herbaceous plants. These at least serve to check erosion and start to rebuild the extremely important litter.

It is impossible to generalize concerning the time which must elapse before reforestation restores conditions in cut-over land to the point where total run-off and seasonal run-off are essentially the same as in the preceding tree generation. Clear cutting has converted some forest types from all-aged to even-aged ones of probably permanently different character. An even-aged stand, for example, must permit of much less wind movement than an all-aged once it has raised its canopy well above the ground. A sprout forest will, of course, restore the conditions more promptly than most seedling forests, because of the early vigorous growth.

This is borne out by the results of a watershed study at the Wagon Wheel Gap in the high mountains of Colorado,[25] in which the Forest Service and the Weather Bureau cooperated. Here for 9 years, 1910 to 1919, stream flow from two adjacent watersheds was measured under undisturbed conditions; then the forest on one watershed was cut. As the forest was mostly aspen, sprouts of this species took possession of the area in the following year, so that the only real result of the cutting was the removal of the conifers which, previous to the cutting, were dominant on about a fourth of the area. Despite the fact that the forest cover was so promptly replaced by sprouts, the total yearly run-off was increased by about 15 percent and the summer run-off was increased by about 10 percent. Flood crests were advanced about 3 days and the maximum height of crest averaged 64 percent greater in the cut-over area than in the undisturbed watershed. As previous to logging the height of the flood crest from the cut-over area exceeded that from the undisturbed area by 6 percent, the net increase amounted to 58 percent. The silt load of the stream after logging increased seven and one-half times.

In most cases, floods due to destructive logging originate on privately owned lands or on unmanaged publicly owned lands.

Overgrazing

FOREST RANGES

Overgrazing on forest lands of the West was without doubt much more widespread 25 to 40 years ago than at present. However, serious depletion of the herbaceous and shrubby vegetation under the trees of the forest or in the openings within the forest—the result of past or present overgrazing—still prevails on enormous areas of forest land. The worst of it occurs in the semiarid regions.

If not utilized too closely the forage produced each year by herbs and shrubs on forested lands is rather well maintained except in the occasional drought year. Investigations of the Forest Service and others clearly indicate that perennial herbaceous plants, principally grasses, were once the chief forage on most forested ranges, and this is still true except where these plants have been depleted. Studies also show that where trees do not grow in sufficiently dense stand to form a close canopy, such as the woodland type, and also in openings in the denser forests, these perennial herbaceous plants if still present are a primary erosion-control agent.

[25] Bates, C. G., and Henry, A. J. Forest and Stream Flow Experiments at Wagon Wheel Gap, Colo. Final report. Mo. Weather Rev. Suppl. 30. 1928.

Overgrazing disturbs the forest cover chiefly in two ways: First by consuming more of the herbage of the more palatable plants than they can withstand, and, second, by increased trampling. Under such overutilization the palatable forage plants are grazed closer and closer, and their vigor is sapped. As these plants produce less forage and their stand is thinned, the less valuable plants are grazed more severely until they, too, are thinned. Studies by the Forest Service show that there are many areas now producing not more than 20 to 30 percent of the forage of which they once were capable, and under such conditions flood run-off and erosion are usually severe.

Forsling [26] has pointed out that depletion of forage is accompanied by severe soil losses without any material gain in the total water obtainable from watersheds in this region. He studied conditions on two subalpine watersheds of about 10 acres each at the head of Ephraim Canyon, Utah. On watershed A, a 16-percent cover, mainly of annuals, was maintained from 1915 to 1920, but was improved gradually until in 1924 it reached 40 percent, made up chiefly of perennial grasses and weeds. In this condition it was maintained through a 6-year period 1924–29. On watershed B, used as a check, a 40-percent cover, largely of perennial grasses and weeds, was maintained for the full period 1915–29. Table 6 presents the comparative data from these two watersheds.

TABLE 6.—*Comparison of surface run-off and sediment removed from two watersheds under different densities of vegetative cover*

Period and watershed	Vegetative cover	Total rainfall [1]	Total surface run-off	Run-off per inch of rainfall	Sediment removed per acre	Sediment per inch of rainfall
	Percent	*Inches*	*Inches*	*Inch*	*Cubic feet*	*Cubic feet*
1915–20:						
Watershed A	16	30.45	1.5084	0.0495	802.9	26.37
Watershed B	40	32.01	.2529	.0079	148.0	4.62
Difference				.0416		21.75
1921–23:						
Watershed A	16–40	17.20	.7618	.0443	315.1	18.32
Watershed B	40	17.43	.2153	.0124	111.9	6.42
Difference				.0319		11.90
1924–29:						
Watershed A	40	25.21	.4914	.0195	114.9	4.56
Watershed B	40	25.96	.2271	.0087	46.4	1.79
Difference				.0108		2.77

[1] All storms coming as rain, or rain with snow and hail, and exclusive of storms that were snow only.

It is significant that the difference in surface run-off in summer rains between the two watersheds is 75 percent less after watershed A reached a reasonably good vegetative condition. It is excessive run-off from summer rainstorms that causes the destructive floods in this locality. In both periods the records available indicate that total surface run-off from summer rains amounted to less than one-twentieth of the total annual surface run-off from the watersheds. Annual soil losses from watershed A in its depleted condition were over 8 tons per acre, nearly 85 percent of which was the result of summer rains. Approximately 133.8 cubic feet of soil per acre were

[26] Forsling, C. L. A Study of the Influence of Herbaceous Plant Cover on Surface Runoff and Soil Erosion in Relation to Grazing on the Wasatch Plateau in Utah. U. S. Dept. Agr. Tech. Bull. 220. 1931.

removed annually from watershed A in the 1915–20 period and only 19.2 cubic feet per acre per year in the 1924–29 period. The difference in sediment removed between the watersheds was strikingly reduced following the improvement in vegetative cover—87 percent between the first and last periods.

Destructive floods have occurred in Utah in the last 10 years in the thickly populated area near Salt Lake. Studies made by Prof. Reed W. Bailey of the Utah Agricultural College, in cooperation with the Intermountain Forest and Range Experiment Station and the Utah State Land Board, have shown that the 75-foot or deeper channel cutting and the enormous amounts of waste debris deposited by these recent floods were far in excess of any earlier flood action i that locality since the geologic Lake Booneville ceased to exist some 30,000 or more years ago.

After the floods of 1930 the Governor's special flood commission established the fact that the waters heavily laden with silt had collected chiefly on small areas of private land at the heads of the drainages where the vegetative cover had been destroyed or seriously depleted by overgrazing, fire, and to some extent by logging. These areas are badly gullied and the surface soil has been stripped away through sheet erosion. Slopes, too steep for grazing, that at intermediate elevations make up the greater part of the mountain face, bear a substantial brush or forest cover. No gullies originated on these densely vegetated slopes, where the thick litter cover and the large humus content in the surface soil permitted effective penetration of water and restrained the surface flow sufficiently to prevent undue soil or water losses.

The open range is only less important than the forest range because much of it occurs under semiarid conditions. The same factors of overgrazing that are responsible for destructive floods and accelerated erosion from forest ranges are responsible for similar floods and erosion from the open range. About 85 percent of the flow of important western streams comes from over 230 million acres of which 79 percent is range land. Serious erosion occurs on over 350 million acres draining into these streams. Serious and damaging local floods are concomitant with overgrazing. Most of these floods and erosion is due to the misuse of land either in private ownership or in the public domain. (For a more complete description of flood and erosion conditions under range conditions see Watershed Protection, by Reed W. Bailey, and C. A. Connaughton in The Western Range. S. Doc. 199, 74th Cong. 1936.)

WOODLAND PASTURES

In pastured farm woodlands of the Middle West, studies by the Central States Forest Experiment Station show that overgrazing results in the destruction of the sprouts of hardwood timber species, and that trampling of the livestock tends to destroy the litter and compact the soil, making it less receptive of precipitation and subject to erosion. Under extreme use, such as occurs in the Corn Belt where many farm woodlands are used as much for shade as for the feed they produce, practically the entire understory of vegetation and the litter covering the soil has been destroyed. When such a situation has developed the topsoil is invariably lost.

Bates and Zeasman [27] have shown, on comparable soils, that, from a plot in pastured oak woodland with a slope of 38 percent, 13 percent of the rain ran off, while from a dense unpastured oak forest with a slope of 42 percent only 0.2 percent ran off and only 2 percent from open unpastured oak woods with a slope of 49 percent ran off.

Weaver and Noll [28] in a study of the water relations of barren, grazed, and fully vegetated soils obtained results similar to those reported from Wisconsin. From barren soils 15.1 percent of the rainfall ran off, from the pastured areas 9.1 percent, and from the area with a full vegetative cover only 2.5 percent. Following heavy artificial applications of water it was found that 5 days after the application the moisture had penetrated to only 19 inches in the bare soil, 22 inches in the pastured soil, and to 42 inches in the soil supporting the full prairie vegetation.

Auten (op. cit.) has shown in his studies of grazed and ungrazed areas in Ohio and in the Ozarks that the top layers of grazed soils averaged 15 percent heavier than those of ungrazed soils. The heavier and more compact soils, moreover, were distinctly inferior to the light, porous soils from ungrazed woods in ability to absorb repeated applications of water. The reduced absorptive capacity of soils from grazed woodlands is a reflection of the lack of litter which characterizes such areas, fully as much as of the trampling by the livestock which destroys the surface network of roots and packs the soil.

The work of Stewart [29] reveals the same tendency in New York State for long-continued grazing use to reduce permeability and water storage of soils.

The relation between land use and floods has been clearly demonstrated at the Upper Mississippi Erosion Station at La Crosse, Wis. This station is maintained by the Lake States Forest Experiment Station in cooperation with the Soil Conservation Service and the University of Wisconsin. The experimental area consists of a typical upland farm devoted to dairying.

Among the experiments carried on at this station is an investigation of the comparative watershed protection value of cleared pastures, pastured wood lots, and unpastured wood lots.

The results of this experiment contribute tangible knowledge of the part which cleared pastures and grazed and ungrazed wood lots play in preventing run-off and erosion on steep slopes. Three small watersheds have been selected; one, a pasture recently cleared of timber; the second, a watershed covered with typical hardwood forest which is being pastured; and the third, a typical wood lot upon which no grazing of any kind is permitted. These three watersheds are separated by diversion ditches from the cleared land above so that only precipitation which falls within the boundaries of these tracts is actually measured as run-off at the lower end of the waterways which drain them. The results of these measurements are very illuminating in that they show the effect land use has upon the volume of run-off and the amount of erosion that occurs.

The calendar year of 1935, although the precipitation was not markedly above the normal of 30.81 inches, was characterized by

[27] Bates, C. G. and Zeasman, O. R. Soil Erosion, Wisc. Agric. Expt. Sta. Res. Bul. 99, 1930.

[28] Weaver, J. E. and Noll, W. C. Comparison of Run-off and Erosion in Prairie, Pasture, and Cultivated Land. University of Nebraska. Contribution from the Dept. of Botany. No. 96, 1935. pp. 37.

[29] Stewart, G. R. A Study of Soil Changes Associated With the Transition From Fertile Hardwood Forest Land to Pasture Types of Decreasing Fertility. Ecological Monographs, January 1933.

eight storms of rather high intensity. During the period August 1 to 6 there were several successive storms which caused one of the worst summer floods experienced in southwestern Wisconsin for several decades. The year 1935 was, therefore, an especially good year to test the effectiveness of the different types of vegetation and land-use upon run-off and erosion.

Of the total rainfall occurring during the period May to November, the recently cleared pasture yielded 3 percent in the form of run-off. The timbered wood lot which was grazed, yielded about 9 percent run-off, but the timbered and ungrazed watershed only 0.15 percent run-off. The total amount of soil washed away during the same period amounted to 600 pounds per acre for the cleared pasture, 1,600 pounds per acre for the grazed, wooded watershed, but only 17 pounds per acre for the ungrazed, timbered watershed.

The quantity of run-off and the amount of soil eroded from these three watersheds varied with the intensity of each storm. Thus, during the 4-hour storm of August 5, when some 2.4 inches of rain fell, the cleared-grazed watershed yielded 6 percent in the form of run-off, the grazed-wooded watershed 17 percent, and the ungrazed-wooded watershed 0.7 percent of the precipitation falling on these respective watersheds. The soil loss during this same storm amounted to 220 pounds per acre for the cleared pasture, 745 pounds per acre for the wooded and grazed pasture, and only 17 pounds per acre for the ungrazed wood lot.

During the eight most intense storms of the summer of 1935, run-off and soil loss occurred only twice from the ungrazed and wooded watershed, and then in quantities so small as to be insignificant. This watershed thus demonstrated its ability to absorb completely rainfall ranging from three-fourths inch to 2 inches. This timbered watershed, it seems, has practically unlimited capacity to absorb and store summer rainfall.

It would seem also that a cleared pasture, if it is not overgrazed, as is the case at the La Crosse farm, develops a thick, dense, bluegrass sod which affords better watershed protection than a sparsely timbered, grazed wood lot. The reason for this is not hard to find. Grass under the shade of trees does not grow well and, as a consequence, the stock must cover the ground more completely in their efforts to obtain forage. This, of course, means that the soil becomes quite hard and compact through trampling. On the other hand, the grass in open pastures develops luxuriantly and offers more obstruction to water moving along the surface of the ground, and thus greater absorption of moisture takes place. This is why good sod is more capable of preventing run-off and erosion than heavily grazed timberland. The moral, of course, is that a forest, if it is to exercise fully its watershed protection value, should be dense, ungrazed, and have a thick undergrowth of shrubs and herbaceous vegetation.

What do these figures mean? There are in southwestern Wisconsin some 2,000,000 acres of wood lots. Approximately three-fourths of this area (1,500,000 acres) has been burned over, has a sparse timber cover, and is grazed. If the figures obtained at the La Crosse erosion station for the period May to November 1935 are used as a basis, these wood lots in their present condition contributed some 5,700,000,000 cubic feet of run-off and 1,185,000 tons of soil to the Mississippi and its tributaries during the past season. This volume of water is equivalent to 10 days of severe flood on such a stream as the Cannon River

of Minnesota, a stream which drains over 1,300 square miles of land. For periods of excessive rain, such as the storms of August 1–6, the run-off from the 1,500,000 acres of grazed timberland may mean the difference between the disastrous floods and merely high-water stages in southwestern Wisconsin. If, on the other hand, these 1,500,000 acres of wood lots were protected from fire and grazing, they could prevent during a season such as the one just passed 5,700,000,000 cubic feet of water and 1,185,000 tons of soil from getting into the streams. If all of the land in this region could be similarly controlled, there would remain practically no possibility of summer floods.

Although the experiments were carried on in Wisconsin, the results are equally applicable to southeastern Minnesota. There are in Minnesota some 452,250 acres of grazed wood lots in a similar condition, which, on the same basis of appraisal, contribute 1,721,945,000 cubic feet of run-off and 357,277 tons of soil. Under proper handling of the wood lots the streams could be largely relieved of this unnecessary burden.

Smelters

Fumes from smelters and other industrial plants may completely destroy or injure forest and other vegetation. Destruction by smelter fumes is found near Ducktown, Tenn., Kennett, Calif., Anaconda, and Butte, Mont., and in the vicinity of a number of other smelters located within forested areas. Large areas around them demonstrate to a superlative degree the debt mankind owes to vegetation for its influence on surface run-off and erosion and the price we must pay when we destroy it. At Ducktown, an area of from 10 to 12 square miles around the smelters has become denuded of natural vegetation with the exception of occasional clumps of sage grass and wild smilax. Bordering this barren region is one varying from 1 to 5 miles in width, covered with sage grass, vines, and a few stunted shrubs and small trees, the latter often with dead tops. Beyond this border of almost treeless vegetation the country is not heavily wooded for some distance, the growth being unthrifty and trees with dead or dying tops being numerous.

Glen (op. cit.) states that the annual rainfall in the region is 50 to 60 inches, and often torrential, so that during the downpours soil surfaces almost literally melt away. The wasted soil accumulates along the stream courses. He states further:

> On Potato Creek this waste has been accumulating for a number of years at the rate of a foot or more each year, and has been built into a flood plain from 100 to 300 yards wide, in which telephone poles have been buried almost to their cross arms and highway bridges, roadbeds, and trestles have either been buried by the debris or have been carried away by floods. * * * The normal flow of Potato Creek is said to be only about half as large as it used to be, and there can be no question that a much larger part of the rainfall now finds its way immediaately into this stream and is carried off in floods, leaving a much smaller part to soak into the ground to supply the wells, springs, and streams during periods of dry weather.

Near Kennett, Calif., all vegetation has been destroyed on an area upward of 67,000 acres and partial destruction has occurred on 86,000 acres additional. Without the protecting vegetative cover, the surface soil of the denuded portions was soon washed off, exposing an inert subsoil which continues to wash and gully at a rapid rate. Munns [30] estimated a total of more than 35 million cubic yards had

[30] Munns, E. N. Erosion and Flood Problems in California. Calif. State Bd. Forestry Rpt. to the Legislature 1921 on Sen. Con. Res. 27. 1923.

been removed from the Kennett area in 10 to 15 years. Conditions are very similar in other smelter areas.

ABANDONED AGRICULTURAL LANDS

Hundreds of millions of acres once in forest have been cleared for crop production. This was a natural process in the settlement of the United States. At the time many were cleared little was known of the productive capacity or the erosiveness of the soils, and it is natural that many areas have later proven to be unsuited for permanent agricultural use. In 1933 the Bureau of Agricultural Economics estimated that there were over 50 million acres of cleared land, which, abandoned or idle, were available for reforestation. Of these probably 11 million will require artificial reforestation. Present trends indicate an additional abandonment of some 25 or 30 million acres of potential forest land in the next 20 years.

These areas, abandoned or in process of abandonment, have largely passed such usefulness as they had for crop production. Many owe their abandonment to loss of productivity through erosion of the fertile topsoil and in some instances of large amounts of the subsoil. They are found most often in hilly and mountain regions, in regions of more level topography but having soils which erode with extreme ease, and in regions where the soils do not erode readily, but where the topsoil is so shallow and the subsoil so unproductive that the loss of a few inches of soil by erosion renders them practically worthless. These lands are widely distributed east of the Great Plains, but are found in parts of the West as well.

The flood menace presented by these depleted and abandoned areas is strikingly shown by continuous records in the Appalachian region of the run-off from abandoned and eroded lands and from forested land. Records have been compiled of the continuous flow of streams from 23 small watersheds, representing different types of forest and other vegetative cover conditions for periods of from 1 to 2½ years. They show that for the 12 months' period, July 1, 1934, to June 30, 1935, the average maximum flood-flow for all the forested watersheds amounted to only 38 cubic feet per second per square mile; for grassed and abandoned agricultural land, 432 cubic feet per second per square mile; and for completely denuded land, 1,304 cubic feet per second per square mile. In no case did the storm run-off from forested watersheds assume critical flood conditions, whereas from the nonforested watersheds numerous instances were recorded on which the maximum flood assumed very serious flood proportions. In Macon County, N. C., the maximum flow from 4 forested watersheds ranged from 16 to 24 cubic feet per second per square mile. Results from other typical watersheds under observation are presented in tables 7 and 8.

TABLE 7.—*Streamflow records from small watersheds in Oconee County, Tenn.*

Watershed:	*Maximum rate of flow, cubic-foot seconds per square mile*
Forested no. 1	30
Forested no. 2	56
Incomplete broomsedge cover no. 3	832
Incomplete broomsedge cover no. 4	900
Denuded, no cover no. 5	1, 263
Denuded, no cover no. 6	1, 434

TABLE 8.—*Streamflow records from small watersheds, Buncombe County, N. C.*

Watershed:	*Maximum rate of flow, cubic-foot seconds per square mile*
Forested no. 1	32
Forested no. 5	13
Forested no. 6	15
Overgrazed pasture no. 3	579

Through the adoption of contour plowing terracing, crop rotation, and other suitable methods of cultivation doubtless much of the slightly eroding agricultural land can remain in crop production or in pastures. Such land is beyond the scope of this report. On most of the 50 million acres of abandoned lands, however, the loss of soil productivity has reached such proportions that cropping methods cannot be expected to overcome the active erosion and hazards of agricultural production. As Bennett [31] has stated:

When the mellow topsoil is gone, with its valuable humus and nitrogen, less productive, less permeable, less absorptive, and more intractable material is exposed in its place. As a rule this exposed material is the "raw" subsoil, which must be loosened, aerated, and supplied with the needed humus to put it into the condition best suited to plant growth. This rebuilding of the surface soil requires time, work, and money. In most places this exposed material is heavier than the original soil, is stiffer, more difficult to plow, less penetrable to plant roots, less absorptive of rainfall, and less retentive of that which is absorbed, and apparently its plant-food elements frequently have not been converted into available plant nutrients to anything like the degree that obtains in the displaced surface soil. * * * Such raw material must be given more intensive tillage in order to unlock its contained plant food, and on much of it lime and organic muanres will be needed in order to reduce its stiffness sufficiently to make it amenable to efficient cultivation, to the establishment of a desirable seed-bed tilth. It bakes easier and, as a consequence, crops growing on it are less resistant to dry seasons, because of rapid evaporation from the hardened surface, and the many cracks that form deep into the subsoil to enlarge the area exposed to direct evaporation. Crops also suffer more in wet seasons because the material becomes more soggy or waterlogged than did the original soil. On much of it both fertilizer and lime will be required for satisfactory yields.

While these difficulties of tillage and the lowered productivity are being attended to by the farmer in those fields not yet abandoned, the unprotected fields continue to wash. Unfortunately the farmers in many localities are doing little or nothing to stop the wastage and much to accentuate it.

Even on moderate slopes the soil losses from the cultivated fields on certain soil types, under unfavorable climatic conditions, are enormous. Forest Service studies at Holly Springs, Miss., in the loessial-soil belt, show that a single torrential rain falling on a cornfield having a 10-percent slope washed soil from a study plot at the rate of 23 tons per acre. Preliminary results show that under such conditions only 2 to 3 years are required to wash away 1 inch of topsoil. These data, substantiated by observations, indicate that the cultivable life of these upland soils ranges from 5 to 20 years. Yet the serious danger of erosion from the cultivation of fields of slight slope in this region which have readily erosible soils is not so generally recognized and many such fields are being cleared and plowed to take the place of other fields which have lost their productivity. Bennett points out (op. cit.) that—

some soils cannot be cultivated without steady decline due to erosion, even where the slope does not exceed 1 or 2 percent. The Knox silt loam, for example, is such a soil. On this soil erosion goes on in all tilled fields where there is any slope whatever.

[31] Bennett, H. H., Part I. Some Aspects of the Wastage Caused by Soil Erosion, pp. 1–3. Dept. Agr. Circ. 33, Soil Erosion a National Menace. (H. H. Bennett and W. R. Chapline) 1928.

The high run-off from slight slopes if further shown by Fuley and Hays [32] in their studies in Kansas. They found run-off increased rapidly as the slope increased from 0 to 3 percent grade. Over 63 percent ran off with a 2 percent grade in their experimental tank. The increase in run-off was then very slight for each 1 percent of increase in slope, reaching about 86 percent with a slope of 20 percent grade. Erosion, on the other hand, increased gradually until the slope was about 4 percent; then the increase was found to be more rapid up to about 7 or 8 percent; after which there was a still greater increase in the rate at which the soil was removed from the plots.

If level agricultural land were scarce in the United States and there were a great need to increase crop production, very intensive farm management could unquestionably be applied to rather steep slopes to meet the situation. Under existing circumstances, however, it seems likely that clearing new ground on slopes of over 10 to 15 percent is destined eventually to swell the area of abandoned land and add to the problem of reclaiming gullied lands by reforestation.

Thus, much of the flood run-off and much of the eroded material that appears in streams draining agricultural lands is due primarily to the misuse of privately owned agricultural lands. Floods on such streams as the Allegheny, Susquehanna, Connecticut, Potomac, Santee, and Yazoo have been greatly augmented by agricultural land misuse.

INFLUENCE OF FOREST COVER

That stream flow and erosion are greatly influenced by the kind and condition of forest and other vegetative cover has been shown in preceding sections. Profound changes have taken and are taking place in the regimen of our streams, and undesirable soil movement has taken and is taking place on great areas of watershed land. These changes, usually harmful in their effect, have been shown to be largely the result of improper use of forest, range, and farm land.

The degree of a forest's influence on watershed functioning depends on (1) the type and condition of the forest, (2) the characteristics of the soil, (3) the topography, and (4) the intensity and purpose of water use. A classification of the forest areas of the United States as to watershed-protective value, on the basis of these factors, is presented in table 9.

Almost three-fourths of the total forest area of the United States has been classified as watershed-protection forest, that is, as having major or moderate influence on watershed values. The remaining fourth, because of flat topography or extremely permeable soil or for other reasons, is considered to have slight influence or none. Of the watershed-protection forest, about two-thirds, or 308 million acres, exerts a major influence and one-third, or 141 million acres, exerts a moderate influence.

[32] Duley, F. L., and Hays, O. E. The Effect of the Degree of Slope on Run-off and Soil Erosion. Jour. Agr. Research, vol. 45, no. 6: 349–360, 1932.

TABLE 9.—*Watershed protective value of forests in the United States*

Drainage basin	Total land area	Total forest area	Forest area by watershed-protective influence		
			Major	Moderate	Slight or none
	Thousand acres	*Thousand acres*	*Thousand acres*	*Thousand acres*	*Thousand acres*
East:					
Northeast	78,428	42,725	17,320	13,387	12,018
South Atlantic	62,812	43,581	29,204	6,412	7,965
East Gulf	105,388	73,313	18,709	4,335	50,269
West Gulf	123,926	36,736	2,921	20,678	13,137
St. Lawrence	84,616	42,246	5,029	4,112	33,105
Hudson Bay	24,960	6,400	66	81	6,253
Total	480,130	245,001	73,249	49,005	122,747
Mississippi River Basin:					
Upper Mississippi	119,586	28,094	5,694	4,429	17,971
Ohio River	130,421	45,391	35,919	7,569	1,903
Missouri River	327,447	28,642	20,515	6,769	1,358
Arkansas-Red	176,981	52,220	34,560	15,525	2.135
Lower Mississippi	33,720	17,854	6,857	1,877	9,120
Total	788,155	172,201	103,545	36,169	32,487
West:					
California	70,744	29,780	21,056	3,736	4,988
Colorado	154,880	45,070	36,196	8,829	45
Rio Grande	108,160	17,460	14,168	3,292	
Great Basin	138,455	19,534	5,513	12,021	2,000
Columbia	131,119	59,025	38,745	18,180	2,100
Pacific Cascade	31,648	26,487	15,564	9,509	1,414
Total	635,006	197,356	131,242	55,567	10,547
Grand total	1,903,291	614,558	308,036	140,741	165,781

The fact that the extent and character of the forest cover, as well as stream flow and erosion, are controlled in part by the quantity and distribution of precipitation makes it difficult to draw deductions from gross acreages. It may be noted that in the Pacific Cascade drainages, with steep slopes and heavy rainfall but with about 90 percent of the total area in forest, mostly dense, floods are no great cause for concern, while in the Colorado River Basin, with much lower rainfall but with less than one-third of its area in forest of a lighter type, floods and erosion are serious. The effect of forest destruction on run-off is indicated by studies at the Red Plains Erosion Experiment Station in Oklahoma, where a plot from which the forest litter had been burned produced more than 100 times as much run-off as a similar unburned plot; its effect on erosion is indicated by a study of Hoyt and Troxell in California, in which the flood flows from burned watersheds were found to contain 20 to 67 percent of ash and silt.

The Great Basin, with only 14 percent of its area forested and only 28 percent of this classed as of major influence, developed a serious flood and erosion situation only after the forest and other vegetative cover was reduced by overgrazing and fire. Similarly, in the Ohio River Basin, 35 percent of which is in forest, the silting problem and increased frequency of floods have followed misuse of the land by man.

Erosion is a geologic phenomenon older than the hills, yet in each region the original vegetative cover was usually sufficient for soil building. Reduction of the cover through timber cutting, fire, overgrazing, and cultivation has often not only prevented soil building but diminished the fertility of the existing soil and impaired its ability to produce cover of the original type. On an immense area the forest

cover has been reduced or removed by fire and improper cutting. The vegetative cover has too often been depleted by improper grazing methods, and the fertile topsoil has been washed from millions of acres of agricultural lands. The result of this land treatment has been higher and more frequent floods, silted reservoirs, and stream channels, accentuated difficulties during periods of low water, and reduced productivity of the land.

RELATION OF OWNERSHIP TO WATERSHED CONDITIONS

Land ownership, more than any other one factor, has determined the differences in present watershed conditions. The degree to which watershed requirements have been met on land in various types of ownership and the sort of action necessary to establish satisfactory watershed management in each of these types are substantially as follows:

Private Ownership

AGRICULTURAL LAND

In the eastern half of the United States the most acute flood and erosion problems exist on land now classed as agricultural. On such land, according to rough calculations, perhaps 70 percent of the erosion takes place and 40 percent of the water troubles originate. More than 50 million acres of agricultural land in the United States is now abandoned or idle, and present trends indicate the abandonment of an additional 25 or 30 million acres in the next 20 years. Largely because of removal of fertile topsoil, often through sheet erosion, the productivity of nearly all the land now abandoned was reduced below the point at which the land could be used economically for crop production.

Erosion on agricultural land is by no means confined to abandoned land or land approaching abandonment. Under present cropping methods erosion is the usual condition, and unless present practices are remedied more and more of the fertile soil from farm lands generally will be added to the silt load of streams and rivers. On land suited for agricultural use, the problem is one to be solved by agriculture rather than by forestry.

These conditions are in part the result of cultivation on slopes so steep and soils so erosive that destructive washing was inevitable. Failure to hold the soil on lands that could have remained in agriculture by contour plowing, terracing, and proper crop rotation has been another contributing factor. We are now faced with the problem not only of putting this once productive land to use but also of preventing it from doing positive damage through increased contribution to flood run-off and through the silting of stream channels. That this land does accentuate these two problems immensely is shown by many experimental results already reported.

Since private ownership did not meet watershed requirements on these lands even while they had agricultural value, obviously it cannot be expected much of it will voluntarily assume the expense of rehabilitating these lands or of controlling erosion and flood run-off from them. The situation calls for public acquisition and management of areas that can be blocked up into feasible administrative units and of smaller units where the flood contribution is extremely

large and where private initiative plainly cannot be expected to correct conditions. Public acquisition can come in part through tax delinquency and in part through gift or purchase.

On a large part of this land a cover of grass, weeds, brush, and trees sufficient to hold the soil will come in naturally if cropping is permanently eliminated and the cover is protected from fire and overgrazing, but on some 10 or 11 million acres in more humid regions the gullying that has started can best be stopped by reforestation.

FOREST LAND

Private ownership of forest land has usually carried with it no consciousness of an obligation to manage the lands so as to maintain or improve watershed conditions. In cutting timber it has generally been the owner's purpose to harvest the existing timber and dispose of the cut-over land as soon thereafter as possible. Only a small part of the 10 million acres of private timberland cut over annually is cut in such a way as to bring about perpetuation of the forest. Cutting practices designed to promote natural reproduction have been adopted on only about 10 million of the 444 million acres of privately owned forest lands. That present owners do not intend to retain possession permanently is implied by the fact that, even prior to the present depression, great areas of cut-over land in the Lake States, the South, the Pacific coast, the northern Rocky Mountains, and other regions had become tax delinquent.

Too often, logging methods have been used that were extremely damaging to young growth left standing and that induced rapid run-off and erosion. Broadcast burning of slash in the ponderosa pine and other types has been curtailed in recent years only.

Fire control on private timberlands is inadequate in all regions of the United States with the possible exception of the northern and southern Rocky Mountains. The best available data show that only about 54 percent of the 412 million acres of private timberlands needing protection are receiving it. More than 150 million acres of private forest land in the 11 Southern States and more than 35 million acres in the Central States receives no protection. Partly as a result of this fact, the area burned over annually in the 5-year period 1926–30 averaged more than 37½ million acres in the South and 1,379,000 acres in the Central States. In some western regions there has been a tendency to withdraw protection from cut-over lands where such action does not jeopardize virgin timber.

Grazing on private timberlands has likewise failed to meet watershed requirements. In the East, grazing use of woodlands has often been so heavy as to destroy the litter cover, pack the soil, and prevent the establishment of young trees in the stand. In the West, where range forage on timberland is usable it has been sold without serious attempt to regulate use in such a way as to maintain the vegetative cover. The proportion of the 228 million acres of privately owned forest land used as pasture on which watershed management receives even incidental consideration is insignificant.

Partly as a result of the practices just mentioned, about 56 million acres of privately owned forest land in the United States has been devastated. The Lake States with 12 million acres, the South with 23 million acres, and the Northeast with 5 million acres of such devastated land clearly illustrate the lack of concern for forest values.

So long as the treatment of private land does not damage other land or the public, public intervention is not called for. Where bad management will result in irregular stream flow floods, erosion, or otherwise damage public or private property, certainly management restrictions are justified. They cannot properly be applied, however, unless the public is willing to bear its share of the expense which such action may entail. As an alternative to regulation the only recourse seems to be public acquisition of critical watershed areas.

The importance of privately owned forest land to watershed protection is shown in table 10. Certainly, with a total of 297 million acres of privately owned forest land classified as of high and moderate watershed influence, the condition of such land is a matter of public concern.

Town, Municipal, and County

Town and municipal forests, which total about 500,000 acres in the United States, are in general very well cared for. Usually they have been established for watershed protection. They are policed and protected, and cutting and grazing are either banned or so regulated as to permit maintenance of favorable cover conditions. Denuded lands are usually planted as acquired.

Table 10.—*Watershed-protective influence of privately owned forests*

Drainage	Total forest area	Forest area by watershed-protective influence		
		Major	Moderate	Slight or none
	Acres	*Acres*	*Acres*	*Acres*
Northeastern	38, 587, 000	14, 544, 000	12, 601, 000	11, 442, 000
South Atlantic	42, 137, 000	28, 444, 000	5, 913, 000	7, 780, 000
East Gulf	72, 187, 000	18, 480, 000	4, 248, 000	49, 459, 000
West Gulf	36, 588, 000	2, 916, 000	20, 588, 000	13, 084, 000
Lower Mississippi	17, 842, 000	6, 847, 000	1, 877, 000	9, 118, 000
Arkansas-Red	48, 775, 000	32, 040, 000	14, 871, 000	1, 864, 000
Ohio	43, 532, 000	34, 268, 000	7, 429, 000	1, 835, 000
Upper Mississippi	26, 730, 000	5, 624, 000	4, 329, 000	16, 777, 000
St. Lawrence	34, 696, 000	4, 828, 000	2, 764, 000	27, 104, 000
Hudson Bay	5, 513, 000	66, 000	76, 000	5, 371, 000
Missouri River	14, 483, 000	12, 262, 000	1, 521, 000	700, 000
California	13, 753, 000	10, 009, 000	2, 086, 000	1, 658, 000
Colorado	6, 482, 000	2, 844, 000	3, 638, 000	
Rio Grande	7, 787, 000	6, 154, 000	1, 633, 000	
Great Basin	3, 851, 000	1, 856, 000	1, 497, 000	498, 000
Columbia	17, 189, 000	12, 438, 000	4, 743, 000	8, 000
Pacific Cascade	14, 225, 000	8, 576, 000	4, 781, 000	868, 000
Total	444, 357, 000	202, 196, 000	94, 595, 000	147, 566, 000

State

State-owned forest lands total more than 13 million acres, including 4,395,549 acres of State forests, 2,682,509 acres of State parks, and 6,140,106 acres in other status.

In the Pacific Coast and Rocky Mountain States, State ownership generally goes back to Federal land grants made without regard to the major purpose which the land should serve. In New England and the Middle Atlantic States, State ownership has more often resulted from direct acquisition, and in some instances is based in part on watershed-protection needs. In some regions, including the Lake

States, State ownership has resulted in part through Federal grant, in part through purchase, and in part through tax delinquency. Obviously, in such cases watershed value was not the primary basis of selection. Table 11 shows by regions the watershed-protective influence of forest lands in State, municipal, and county ownership.

TABLE 11.—*Watershed-protective influence of forests on State, county, and municipal lands*

Drainage basin	Total forest area	Forest area by watershed-protective influence		
		Major	Moderate	Slight or none
	Acres	*Acres*	*Acres*	*Acres*
Northeastern	3,545,000	2,500,000	500,000	545,000
South Atlantic	232,000	100,000	82,000	50,000
East Gulf	250,000	50,000	5,000	195,000
West Gulf	148,000	5,000	90,000	53,000
Lower Mississippi	12,000	10,000	----------	2,000
Arkansas-Red	105,000	70,000	14,000	21,000
Ohio	282,000	150,000	64,000	68,000
Upper Mississippi	1,175,000	70,000	100,000	1,005,000
St. Lawrence	5,115,000	200,000	1,328,000	3,587,000
Hudson Bay	17,000	----------	5,000	12,000
Missouri	411,000	200,000	163,000	48,000
California	121,000	111,000	----------	10,000
Colorado	1,797,000	1,200,000	595,000	2,000
Rio Grande	1,069,000	1,000,000	69,000	----------
Great Basin	122,000	15,000	5,000	102,000
Columbia	2,021,000	835,000	1,000,000	186,000
Pacific Cascade	1,058,000	500,000	227,000	331,000
Total	17,480,000	7,016,000	4,247,000	6,217,000

Most State lands organized as State forests or parks are so managed and protected that watershed values are maintained and improved. In some Eastern States cutting is closely supervised, grazing is restricted, fire is virtually excluded, and most of the denuded areas have been planted. In some States, because of lack of interest in State forests, protection is inadequate, grazing and cutting are virtually unregulated, and little if any progress has been made in reforesting denuded lands.

State-owned forest lands outside State forests and parks in some instances are given little or no administration. Many of these holdings are so widely scattered and in such small parcels as to make management somewhat difficult. In many of the Western States these lands are leased for grazing on an acreage basis without any restrictions as to numbers of stock to be pastured or season of use. In some instances timber is sold by estimate and cutting is not supervised. State lands inside national-forest boundaries, however, are often given protection and other management under cooperative agreements with the Forest Service. In some States there exists a State forestry organization capable of expanding sufficiently to place all State-owned forest lands under administration.

The acreage of organized State forests should be increased greatly. An aggressive acquisition program should be formulated to provide that the tax-reverted holdings will be consolidated for efficient management.

The Act of August 29, 1935, authorizes Federal acquisition of forest lands under cooperative agreements with the States.

Since a large acreage of devastated forest land and submarginal agricultural land will inevitably find its way into State ownership, many of the forested States are faced with a large program of reforestation and fire protection in order to rebuild watershed values. They are also faced with the necessity for developing flood-control measures.

Federal

NATIONAL FORESTS

On the national forests a desirable type of administration is provided for a large area of forest and related wild land. Of the forested area 70 percent has high watershed influence, 24 percent has moderate influence, and only 6 percent has slight or no influence. By far the greater part of this land is located in mountainous sections at the headwaters of major streams.

Fire protection is given all national-forest lands, although in some regions it has not reached a satisfactory standard.

Timber cutting on the national forests is usually handled on the selection system, which is most satisfactory from a watershed standpoint. In certain types, particularly the Pacific coast, Douglas fir and mature western white pine, the present cutting practice is not entirely satisfactory from a watershed-protection standpoint.

Denuded lands are being planted as rapidly as funds will permit. Planting operations to date have covered around 500,000 acres. This work should be greatly speeded up.

On the whole, national-forest administration takes into account the needs of watershed protection and in a very practical way applies the available information as to protection of watershed values. Administration is constantly improving, and it is reasonable to expect that the national forests will continue to exert an increasing beneficial influence upon soil and water conditions. It is to be expected that under the guiding policy of the Flood Control Act of 1936, it will be possible to gradually put into effect in the national forests these additional measures which will directly aid the cover and enable it to exert its maximum benefit on run-off.

INDIAN LANDS

Lands in Indian reservations are not, on the whole, given the best possible management from a watershed standpoint. The objectives of timber management are substantially the same as on the national forests. Fire control has been seriously handicapped by lack of adequate funds. Steps have been taken to correct the serious overgrazing which has been practiced on some reservations. The indeterminate status of Indian lands is chiefly responsible for defects in management. Of the 15 million acres of Indian forest land, nearly 70 percent is classified as having high watershed influence.

It is to be expected that as time passes the Indian lands will gradually be brought into a condition which will enable them to furnish greater watershed protection. Already a start in this direction has been made on the Navajo Indian Reservation of Arizona, by the cooperative efforts of the Indian Service of the Department of the Interior and the Soil Conservation Service of the Department of Agriculture.

NATIONAL PARKS AND NATIONAL MONUMENTS

National parks and monuments are generally handled in a way that meets watershed requirements. Commercial use of all kinds is greatly restricted, and in only a very slight degree is this regulated use at variance with best watershed-protection practices. Grazing is gradually being excluded. Commercial cutting is entirely excluded. Fire protection in most of the parks is now of about the same standard as that on the national forests. More than 90 percent of about 4½ million acres of land in national parks and monuments has major or moderate watershed influence. Watershed conditions on these lands are good and are rapidly improving.

PUBLIC DOMAIN

Conditions on the unreserved and unappropriated public domain, mostly in the western drainages, are in decided contrast to those on the classes of Federal lands just discussed. The best available estimates show that 25 million acres of the 173,318,246 acres of the public domain and the Oregon and California Railroad and Coos Bay Wagon Road grant lands is forested. Of the forested land 91 percent has moderate or high protective influence.

Most of these lands are without administration or purposeful management. They suffer from all the evils of improper grazing use, and where timber cutting takes place no provision is made to prevent devastation. Fire protection is entirely lacking on a large part of the watershed lands, and where given is adequate.

About 19 million acres of these lands, because of location and character, might logically be added to existing national forests. An additional area in excess of 3 million acres might well be given national-forest status as new units or held for inclusion in the national forests at a later stage in the national-forest acquisition program.

The proper administration of these lands would promote improvement of watershed conditions in the West, perhaps, more than any other single measure.

PROGRAM FOR ADEQUATE WATERSHED PROTECTION

Land Management Requirements

In order to meet the deficiencies in watershed protection that have just been presented, the following major improvements in land management must be effected:

FIRE PROTECTION

Fire protection on watershed lands must be improved to meet reasonable standards. This will mean giving organized protection to the 190 million acres of forest now unprotected and materially strengthening protection on the units already organized. In particular, protection effort must be greatly strengthened in the South, the Central States, the Pacific Coast States, and parts of the northern Rocky Mountain region.

TIMBER CUTTING

Timber-cutting practice must be improved, at least, to the extent necessary to stop forest devastation. In general, this will mean the adoption, to some degree, of the selective logging system. In many instances it will not decrease the profits of the operation. While this minimum requirement of forestry practice will not insure acceptable future timber yields, it will in most instances prevent erosion and have a measurable effect in establishing improved conditions of water flow.

REFORESTATION

Trees must be planted on 11 million acres of forest lands and submarginal agricultural lands where conditions are critical. This will lead not only to improved watershed conditions but to production of needed additional supplies of wood. Most of the lands that should be planted are now in private ownership. Table 12 gives the approximate acreage that should be planted for watershed protection.

TABLE 12.—*Areas requiring restoration of cover, for watershed protection*

Drainage	Areas requiring restoration of cover: To be reforested	Areas requiring restoration of cover: To be otherwise revegetated	Drainage	Areas requiring restoration of cover: To be reforested	Areas requiring restoration of cover: To be otherwise revegetated
	Thousand acres	*Thousand acres*		*Thousand acres*	*Thousand acres*
Northeastern	500		California	75	100
South Atlantic	2,000		Colorado	150	200
East Gulf	1,000		Rio Grande	50	50
West Gulf	250		Great Basin	50	200
Lower Mississippi	250		Columbia	150	200
Arkansas-Red	750		Pacific Cascade	100	
Ohio Valley	4,000				
St. Lawrence	500		Total	11,325	900
Missouri	1,000	150			

GRAZING MANAGEMENT

Grazing management must be improved, particularly on private lands, and must be introduced on public lands now unmanaged. On forest lands in the East (particularly farm woodlands) and range lands in the West (both private and unmanaged public) where improper grazing use has resulted and is resulting in increased run-off and widespread erosion, management practices must be applied that will not only stop deterioration but permit the vegetative cover to regain its original density and effectiveness.

SPECIAL MEASURES

Special measures are needed in many localities and regions to supplement the natural vegetation. On lands no longer needed for agriculture, reforestation will have to be augmented by devices designed to aid in putting large quantities of water into the soil and to hold the soil against erosion. On range lands, similar measures are being used to aid the return of natural cover depleted by overgrazing, and to aid

in reseeding. Within forests on headwater areas, even in forests which otherwise are in good condition, special measures can be used effectively to supplement the influence of the forest and to retard rapid run-off.

These special measures, some of which partake in part of an engineering character, include such devices as terracing and contour ditching for water conservation, the construction of detention ponds, water-spreading works and check dams on the little rivers, and stream rectification. Such special measures, many of which have been used by foresters of other lands for decades, are just now coming into general practice in America. Much more, however, needs to be done, and the way is paved in the Flood Control Act of 1936 for beginning such work on an extensive scale. Much can be done in other ways: In logging, slash can be scattered in windrows on slopes, and logging operations developed in such manner as to aid in water control; roads, trails, and other improvements can be so constructed as to conserve water. Erosion control on all road cuts and fills should be adopted as a general policy by all road-building agencies.

REHABILITATION OF ABANDONED AGRICULTURAL LAND

About 50 percent of the water-flow problem in the East results from improper agriculture. The remedy is (1) to improve agricultural methods so that erosion will be lessened and soil fertility maintained on supermarginal lands and (2) to rehabilitate through forestry those submarginal lands which contribute to flood problems. Here we are concerned only with the latter. This will involve (1) fire protection to permit natural revegetation or reforestation where possible (2) forest planting on land where flood conditions would otherwise continue, and (3) special measures where needed.

Methods of Meeting Management Requirements on Private Land

The benefits to be derived from proper watershed management in large measure accrue to the public rather than to individual landowners. Except where conditions on the land constitute a demonstrable menace, corrective action should be financed, at least in large part, by the public rather than by the private owner. The greatest watershed problems exist on private land and unmanaged public land. Three avenues of approach are open to the private-land problem, each offering a different measure of promise.

COOPERATION

Public cooperation with private owners on a voluntary basis is the approach that has been followed in this country to date. By public financial aid the owner is encouraged to meet acceptable standards. That this method has failed is clear from the fact that today, after more than 20 years' effort, 46 percent of the private forest land is without organized fire protection and little more than 2 percent is handled in a way that promotes natural reproduction. In some States the private owners are indifferent to the need for fire protection. Private contributions in the West are almost exclusively for

protection of virgin timber rather than for maintaining a satisfactory cover of cut-over land.

If satisfactory watershed management is to be had by this method, much, and perhaps most, of the cost of management will have to be borne by the public. Fire protection, except on virgin timberland, will be principally at public expense. Reforestation of large areas of devastated forest and submarginal farm lands will have to be undertaken or heavily subsidized by the public, and special measures, sometimes costly, will have to be taken, with little or no cost to the owner. Such action, without definite assurance that the land will be permanently managed in such a way as to protect the public investment, has little to recommend it.

PUBLIC REGULATION

Private ownership with public regulation of use is the second possible solution. This approach is common in European countries. The cost would be even heavier than under the cooperative plan. With land abandonment now common, it seems clear that the addition of any expense or of any restrictions on use would simply speed up this trend and result in much needless friction. Like all regulatory measures, this system would depend for its success on public sentiment. Past experiences do not permit optimism with regard to the functioning of unpopular legislation. Regulatory forest laws have been enacted by most of the States, but they do not have adequate public support and have not in general been effectively enforced.

PUBLIC OWNERSHIP

Public ownership and management of major-influence forest land that can be blocked up for satisfactory administration and of agricultural land highly subject to erosion is the third possibility. Obviously it is unnecessary to propose public ownership of land in these classifications that, because of timber or other values, will be managed reasonably well in private ownership. This method would accomplish by direct action what the alternative methods would attempt to bring about through indirection. Under this method the public would of course pay all the cost of management and protection; it would receive, however, not only the benefit of improved watersheds but the more tangible benefits accruing through sale of forest products. In the long run the projects would be self-liquidating.

Public acquisition of major-influence watershed lands appears to be the most logical solution. Present trends indicate that the cost per acre would be low. Federal, State, county, and municipal governments should proceed with the acquisition of such lands as rapidly as such programs can be financed. The act of August 29, 1935, authorizes the acquisition of forest lands by the United States for State forests.

Bringing Unmanaged Public Land Under Suitable Management

On public watershed land now unmanaged the public should redeem the obligations of ownership by instituting management of the type recommended in the foregoing. The public domain is the outstanding example of unmanaged Federal lands.

State and county land now unmanaged should be placed under management as rapidly as possible, although this action will not always be easy. Large aggregate areas are coming into State and county ownership as small tracts of devastated forest or submarginal agricultural land. Comprehensive planning is needed to work out the most feasible division of responsibility and methods of administration. To block the areas up into administrative units would require the purchase of additional lands and exchange of ownership among various public agencies including the Federal Government.

RESEARCH NEEDED

Research on the influence of forests and associated cover on floods and related phenomena has been sadly neglected. Although some work was begun in the Forest Service in 1906, the total effort has been woefully neglected when compared with the need.

In the limited studies that have been carried out prior to 1930, primary emphasis was placed upon watershed research. Valuable and distinctive results have been obtained but much of that really necessary to a proper understanding of the problem remained obscure.

The present attack on the problem now under way in several regions, seems designed to give more direct and conclusive results. It is breaking down the problem into component parts, and studying each intensively. It has approached the problem more directly in determining the influence of litter on water absorption, the use of water by vegetation, the part that forest tree-roots play in holding the soil and in increasing percolation, on the effect of cover on soil freezing aud local climate.

Although this work is now only a few years old, it has developed some stabilizing facts, many of which were little suspected or improperly understood. Data resulting from these studies have been presented earlier. Such work it is believed, will serve not only to give foresters and engineers a better basis of understanding of their mutual flood control problem, but will help the public too to understand more completely how far forests affect floods.

However, the work that has already been done has served to emphasize the need for much more additional research. Such investigations must furnish answers of forest influences in a broad way and to determine the specific supplemental measures needed on forest lands to aid in flood control. They must work out the behavior of the whole water cycle as affected by the natural cover and the use of wild lands.

Beginning sometime prior to 1930, the Forest Service has attempted to develop a comprehensive and well rounded out program of forest influence research. In its preliminary form it was presented to the Senate Appropriations Committee in 1932. Since then it has been greatly revised and amplified.

This research program is to determine the effect of forest, brush, or range cover, or of combinations of them, on floods, streamflow, and related problems. Its purpose is to determine whether such vegetative cover may serve as the major factor in providing satisfactory conditions of water flow on entire watersheds, or important parts of watersheds, and if so, whether it must be used in a virgin condition or may be modified by cutting or grazing. It seeks to ascertain how to conserve moisture for the growing of forest and

forage and how to deliver the maximum amounts of usable water for irrigation, municipal use, power, navigation, etc. It attempts to develop measures applicable to wild lands that surface run-off may be reduced, that water can be absorbed by the soil, and that flow may be made uniform. Its objective is to make waste lands productive, to protect against destructive floods, and to safeguard public and private works, investments which already aggregate hundreds of millions of dollars. In short, it is designed to furnish facts and remedial measures in water control operating on the wild lands as a basis for action by Federal, State, and other agencies.

Practically every watershed in the United States contains some portion of the 615 million acres of forest land or of the 550 million acres of nonforest range land, or both found in our country. The disastrous Mississippi flood, the floods of 1936, and many other floods of recent years, the rapidly increasing demand for irrigation water throughout the West, and the shortage of municipal water for many cities and towns during drought years, greatly accentuate the problem caused by increasing population, and have focused attention on both forest and range as related to streamflow regulation and water conservation.

The work proposed will be done at the regional forest experiment stations, established in accordance with the McSweeney-McNary Forest Research Act of May 22, 1928 (U. S. C. Supp. VII, title 16, sec. 581) and as amended, June 1936. The total cost of this program as developed is about $1,500,000. The regional forest experiment stations and the specific work proposed at each are as follows:

ALLEGHENY FOREST EXPERIMENT STATION

Intensive study in the oak-chestnut-yellow poplar forest of upper Piedmont of the North Atlantic seaboard. Problems of municipal and suburban water supplies become acute with rapidly increasing population and occurrence of such droughts as that of 1930. Floods the cause of much damage. Power production and maintenance of navigation also involved.

Intensive study in the northern hardwoods-hemlock forest of the Allegheny Plateau at the head of the Ohio River drainage. Serious flood problems, illustrated by the Pittsburgh floods of 1907 and 1936, accentuated by extremely close commercial cutting of forest.

APPALACHIAN FOREST EXPERIMENT STATION

Intensive study in the high mountain hardwood forests of the southern Appalachian Mountains. Serious flood and erosion problems. Water used for municipal supplies, power and navigation. Region of mountainous topography, and the heaviest precipitation in the eastern United States. Headwaters of many streams.

Intensive study in the mixed pine and hardwood forests of the Piedmont and upper Coastal Plain of the Carolinas and Virginia. Heavy precipitation and easily eroding lands. Serious flood problems. About 15 million acres of seriously eroded land. Streams and reservoirs silting badly. Region of active lumbering and frequent fires. Forestation only recourse for large area of badly eroded lands.

Intensive study in the complex hardwood forests of relatively low elevations in the Cumberland Plateau, largely tied into the flood and stream regulation problems of the Tennessee Valley. Cumberland Plateau a region of heavy rain, steep slopes somewhat impervious soils, and high flood run-off at the headwaters of the Ohio River.

Supplemental study: Effect of different kinds and degrees of forest cover, slope, and soil, on surface run-off and related problems; consumptive use of water by forest tree species and miscellaneous related studies in mountain hardwoods of Appalachian region.

Supplemental study: Influence of forest cover in natural condition and as modified by clearing, fire, and cutting on local environment in relation to tree growth and on the general climate of the locality.

Supplemental study: Erosion control on road cuts and fills and other national forest construction scars in the Appalachian Mountain region.

CALIFORNIA FOREST EXPERIMENT STATION

Intensive study in the chaparral forests of southern California. Entire present and future agricultural and urban development dependent upon water. Supply very inadequate. Extremely serious local flood and erosion problems. Region of steep slopes and severe local storms. The primary objectives in handling chaparral lands, which are largely in national forests, are the maximum supply of usable water, and flood control.

Intensive study in the pine and fir forests of central California. San Joaquin Valley water supplies insufficient for continued agricultural and urban development. Floods and erosion serious. Timber cutting and use of forest ranges must be made consistent with maximum supplies of usable water and erosion control. Mountainous topography. Heaviest known snowfall which melts rapidly.

Intensive study in the pine and brushfield types of northern California. Headwaters of Sacramento River where flood control and development of major water reservoirs in the State-wide water plan are proposed. Water extremely valuable. Reservoir sites must be maintained against silting. Regimen of navigable streams affected.

Supplemental study in the redwood forest region of California. Serious local erosion problems. Forestation only feasible method of control.

Supplemental study in the brush and forest covered foothills of central California. Twenty million acres badly overgrazed, and repeatedly burned, causing severe loss of soil productivity and grazing value, and affecting irrigation and navigation. A region of severe local winter storms and severe floods.

Supplemental study on the grassland foothills of the central California valleys. Several million acres with excessive sheet and gully erosion, causing floods and silting of irrigation works. Range productivity seriously reduced. Very light rainfall makes reestablishment of cover difficult.

Supplemental study in the sand dunes of the California coast. Harbors, transportation, and other improvements threatened. Twelve hundred miles of shore line involved. Forestry fixation methods must be developed.

CENTRAL STATES FOREST EXPERIMENT STATION

Intensive forest influence study within the hilly, unglaciated region of the lower Ohio Valley in Ohio, Indiana, Illinois, Kentucky, and Tennessee. Problems include reclamation of denuded lands, and determining effect of excessive pasturing and cutting in farm woods on floods and water supplies.

Intensive forest influence study within the Ozark oak region of southern Missouri. This region contributes heavily to major floods in the lower Mississippi River because of heavy rainfall and rapid run-off from steep limestone hills where fire, overcutting, and excessive pasturing of wood lands have impoverished the soil and forest.

Supplemental study on the rolling submarginal lands of the central Corn Belt, on abandoned farms, overgrazed farm woodlands, inland sand dunes, etc., to determine use of water by trees and the part trees play in run-off.

Supplemental influence study on the loessal soils areas of the lower Ohio, lower Missouri, and central Mississippi drainages. Such soils erode easily and contribute materially to the flood and silt burden of the Mississippi.

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Intensive study in the grasslands and open brush and forest areas of the Colorado River drainage. Erosion contributes heavy silt load to the Colorado River and will reduce the effective life of Boulder Dam, and has seriously reduced productivity of range lands. Floods damage farms, irrigation works, highways, and other property. More water is badly needed for irrigation.

Intensive study in ponderosa pine forests of southern Idaho. Cutting of timber on important watersheds questioned because of growing scarcity of water for irrigation. Heavy precipitation, largely snow, and heavy local summer storms make for severe floods from denuded areas. Mountainous topography.

Supplemental study on the mountain grasslands of southern Idaho. Granitic soils. Rapid spring run-off and severe erosion seriously affecting irrigation and power. Range depletion an important factor.

Intensive study in the mountain, foothill, and desert ranges and forests in the Great Basin region of Utah and Nevada. Overgrazing and fires largely responsible for excessive erosion and serious reduction in range productivity. Floods and mud flows from severe summer storms do enormous damage to towns, farms, power and irrigation works. Heavy demand on inadequate irrigation water supply. Restoration of plant cover only feasible method of flood and erosion control.

Supplemental study: Physiographic studies to investigate the physical and biotic factors of site which have a bearing on run-off and soil formation.

LAKE STATES FOREST EXPERIMENT STATION

Intensive study in the swamp forests at the headwaters of the Mississippi to determine the relationship between timber cutting and swamp drainage on floods and water storage.

Supplemental study in the bluff lands and loess soils of the upper Mississippi River. Region of severe local storms and floods. Erosion rapidly destroying valuable land, and has an important bearing upon maintenance of river channels. Forestation only recourse on badly eroded lands and steep slopes.

Supplemental study in the Dakota Badlands. Enormous quantities of silt carried into the Missouri River, greatly increasing the height and severity of floods, the cutting of banks, the difficulty of channel improvement and of navigation. Clay soils very easily eroded. Very scant vegetation.

Supplemental study: Stabilization of sand dunes along the Great Lakes. Five hundred miles of shore line involved. Dunes becoming increasing menace to towns, transportation, and valuable agricultural lands. Forestation only method of control.

NORTHEASTERN FOREST EXPERIMENT STATION

Intensive study in northern hardwood forests of central New England. Floods as in 1936 occasionally do great damage. Problem of stability and quality of water supplies for densely populated municipalities, especially critical during dry years. Power and navigation also involved.

Intensive study in hardwood forests and reforestation areas of central New York on headwaters of navigable streams also serving for municipal water supply. Flood control important because of shallow soils of fine texture.

Supplemental study of the inland dunes in northern New York. Dunes from abandoned farm lands menacing agriculture and transportation. About 150,000 acres involved. Forestry methods for checking dunes should be developed.

NORTHERN ROCKY MOUNTAIN FOREST EXPERIMENT STATION

Intensive study in the western white pine type of northern Idaho and western Montana. Damage by fire to watershed values, on the headwaters of the Columbia River, is extreme. This is reflected in the accentuation of severe flood conditions in the lower Columbia River and in local floods of serious consequence to such communities as Wallace, St. Maries, and Spokane.

Intensive study in the mixed-conifer forest type of western Montana. The major problem is one of flood control. It is also in part one of water supplies for irrigation and power in the Columbia and Missouri River Basins. The effect of fire, cutting, and overgrazing on the regimen of streams will be studied.

Supplemental study in the spring-fall zone of the foothills in central and eastern Montana. Ranges depleted by overgrazing are eroding badly, removing the fertile topsoil upon which range forage production depends. The problem is that of holding back the run-off water.

Supplemental study in the level to rolling short-grass region of the northern Great Plains. Range deterioration or depletion as a result of mismanagement and overgrazing has brought rapid run-off and with it extremely serious wind and water erosion. The original extremely shallow layer of fertile top soil is being removed leaving immense areas which support only worthless annual weeds or prickly

pear cactus. Suitable species of grasses or shrubs and methods restoring the cover by artificial reseeding, or methods of management of livestock permitting natural restoration of the cover must be determined.

PACIFIC NORTHWEST FOREST EXPERIMENT STATION

Intensive study in the heavy Douglas fir forests of western Washington and Oregon. Mountainous topography. Heaviest precipitation in the United States, chiefly in winter. High winter and spring flood run-off and low summer flow. Water of growing importance for municipal and irrigation supplies. More than half of water power resources of United States. Effect of cover and of its management on floods and run-off unknown.

Supplemental study in timber and grasslands of central and eastern Washington. High irrigated land values. Inadequate water for irrigation. Serious flood questions at times. Fine loose, granitic, and volcanic soils.

Supplemental study in forests and ranges of eastern Oregon. Severe loss of soil and water. Lower soil productivity. Local irrigation projects damaged.

ROCKY MOUNTAIN FOREST EXPERIMENT STATION

Intensive study in the open pinon-juniper woodlands and ranges of Colorado. Serious local floods in streams tributary to the Mississippi. Important irrigation and municipal use of water. Rough topography.

Intensive study on the mountainous mixed conifer and grassland watersheds of Colorado and Wyoming. Heavy demand for domestic and irrigation water especially in Platte River Valley. Heavy flood run-off. Inadequate water supplies for present needs of agriculture. Steep topography.

SOUTHERN FOREST EXPERIMENT STATION

Intensive study in the Ouachita Mountain pine forests of central Arkansas. Region contributes very directly and immediately to major floods in the lower Mississippi Valley. Mountainous topography. Severe local and general storms. Relation of fire and cutting of forest cover to flood control the crux of the problem.

Intensive study in the cedar breaks, scrub oak stands, and ranges of the central plateau of Texas. Water needed for irrigation and power. Serious local floods from torrential rains. Both forest and range cover involved. Especially important in Brazos River. Serious problems also in the breaks of the Arkansas and Red Rivers in Texas and Oklahoma.

Supplemental study in the loess soils of the lower Mississippi River. Region of high precipitation and violent storms. Forestation offers only practicable method of controlling flood run-off.

Supplemental study in the pine and mixed hardwood forest of the Piedmont and Upper Coastal Plain. Flood run-off increasing on agricultural and devastated forest lands. Damage to bottomlands and streams. Region of high precipitation and torrential storms.

SOUTHWESTERN FOREST AND RANGE EXPERIMENT STATION

Intensive study in the semidesert brush and grasslands and open forests of Arizona. Precipitation largely in severe local summer storms with high run-off. Water supplies are insufficient, especially in dry years. Run-off seriously depleting range values and causing silting of irrigation works.

Intensive study on open pine forests and intermingled range lands of the Rio Grande watershed. Precipitation principally in summer, floods frequent, water supply inadequate. Overgrazing causing excessive high run-off and erosion. Rapid silting and other destruction of irrigation works.

Supplemental erosion study of grasslands and semidesert range lands, badly eroding and damaging irrigation in New Mexico.

Supplemental erosion study for controlling semidesert and desert lands. About 30 million acres, in Arizona, New Mexico, and adjacent States. Ranges, railroads, roads, and irrigation canals affected. Low precipitation.

APPENDIXES

Appendix A

EFFECT OF COVER ON RUN-OFF IN NORTHERN MISSISSIPPI [1]

Study plots were established during the late summer of 1931 on areas near Holly Springs, Marshall County, northern Mississippi, differing as to cover type and as to land use. A total of 11 plots was used in this study; of these, 8 were used throughout the entire 2-year period, while the other 3 served as duplicates. All plots were rectangular in shape, and were 3 by 12 feet in dimensions.[2] All were laid out on a uniform 10-percent grade, the length of each plot paralleling the slope. Each plot was surrounded on three sides by as trip of galvanized iron 7 inches wide, which was sunk in the soil so that only 2 inches protruded above the surface and was made watertight at the corners. This prevented surface drainage onto the plot from adjoining areas. At the lower end of each plot a galvanized-iron tank was sunk flush with the surface, so as to receive all run-off and eroded material, and was securely anchored.

Run-off and eroded material were measured after each rain or series of rains. When the volume of run-off water in the tanks had been determined by depth measurements, the water was pumped out. The eroded material was then dipped from the tank and weighed, and samples were taken to determine the quantity of dry soil eroded. Rainfall was measured with standard rain gages, one of which was set up near each plot or pair of plots. Data on the intensity and duration of each rain were furnished by a recording rain gage, centrally located.

The soils on which the plots were established were identical in origin. To a depth of 10 to 15 inches they were deprived from weathered loess, a wind-transported soil deposited in Pleistocene times. The loess was underlain by sedimentary materials of the upper coastal plain.[3] The soils on which plots were located varied somewhat in texture and other characters but, for the purposes of this study, were comparable, since they had a similar profile prior to cultivation or other treatment. In some cases the A horizon, which originally was about 6 inches in depth, had been reduced or entirely removed by erosion. A mechanical analysis [4] of composite soil samples from the plots showed that these soils contain a high percentage of silt and clay, especially in the upper 6 inches. At that level the silt-clay content ranges from 53 to 90 percent. At

[1] See also Effect of Cover on Surface Run-off and Erosion in the Loessial Uplands of Mississippi U. S. Dept. Agric. Circ. 347. 1935.

[2] Larger plots could not be used because it was impossible to find areas larger than 3 by 12 feet that were strictly uniform as to conditions of cover, slope, and soil.

[3] Holly Springs sands of the Wilcox formation (Eocene period).

[4] By the Bureau of Chemistry and Soils, U. S. Department of Agriculture.

6 to 20 inches the soils contain less silt and greater quantities of clay and sand.

Duplicate plots were established in (1) a cultivated field, (2) a barren abandoned field, (3) a mature oak forest, and (4) an abandoned field with a cover of native grass. Single plots were established in (5) a 21-year-old plantation of black locust and Osage-orange, (6) a scrub oak woodland, and (7) a Bermuda grass pasture. A description of these areas follows:

The cultivated field which was in corn when the plots were established but was planted to cotton during the study period, represents the more productive portions of the upland region. It was cleared of oak forest in 1927. About 4 to 5 inches of the A horizon was still intact at the beginning of the study. This layer consisted of gray silt loam containing slightly more than 1 percent of organic matter. The herbaceous ground cover consisted chiefly of crabgrass (*Syntherisma sanguinale*).

The first-mentioned abandoned field, formerly in cotton, has not been cultivated since 1924. At the time when the plots were established, most of it supported a scattered growth of scrub oak and persimmon with a ground cover of native grasses; the slope on which the plots were located, however, had no plant cover other than a few dwarfed specimens of poverty grass (*Aristida dichotoma*). Erosion had entirely removed the A horizon, exposing a compact yellow silty clay loam subsoil almost devoid of vegetable matter.

The abandoned field in which the native grass plots were established has been out of cultivation since 1908 or longer. The grass cover consists principally of the so-called broomsedges *Andropogon scoparius*, *A. ternarius*, *A. virginicus*, and *A. elliottii*, which prevailingly compose the grass cover of abandoned and waste areas of the region. The grass on the plots has an average density of more than 0.9. A dense "rough" (matted dead foliage) indicated that the field had not been burned over for at least 4 years before the study began. The soil of the A horizon, which is only 3 inches in depth, is a gray silt loam containing 2 percent of organic matter.

The Bermuda grass (*Capriola dactylon*) pasture was formerly badly eroded as a result of cultivation and abandonment. About 1913 the gullies were filled by means of a plot and a drag scraper, the slopes terraced, and Bermuda grass sod planted. The plot has a complete grass cover. The upper 4-inch layer of soil, representing the A horizon, is a gray silt loam containing slightly less than 2 percent of organic matter.

The mature oak-forest area represents cover and soil conditions such as existed on the other areas prior to cultivation or other treatment. The forest is made up of trees approximately 75 to 100 years old, and averages about 175 trees per acre from 5 to 28 inches in breast-height diameter. It consists chiefly of southern red oak (*Quercus rubra*), post oak (*Q. stellata*), and black oak (*Q. velutina*), with such minor species as dogwood (*Cornus florida*) and persimmon (*Diospyros virginiana*). Southern red oak makes up 75 percent of the stand. During the growing season the density of the crown canopy above the plots is approximately 0.6. This forest is fairly typical of the remaining bodies of upland hardwood forest in the region. It differs from the average mainly in not having been burned over since at least 7 years prior to the beginning of the study. Underbrush and

herbaceous ground cover are almost entirely lacking owing to light grazing, chiefly by hogs. The duff averages 1½ inches in depth and is underlain by one-half inch of black-leaf mold. The soil of the A horizon, which is about 6 inches in depth, is a dark gray silt loam, loose and granular, containing 3 percent organic matter.

The scrub-oak woodland represents extensive stands of second-growth woodland in this section that are inferior in quality as a result of severe cutting, annual fires, and other abuses. The stand consists of blackjack oak (*Q. marilandica*) with some post oak, persimmon, dogwood, and sassafras (*Sassafras variifolium*). It is dense, containing about 1,500 stems per acre. The trees range from 1 to 3 inches in breast-height diameter and from 10 to 20 feet in height. A blackjack oak, 24 inches in breast-height diameter and 49 feet high, overtops the oak thicket in which the plot is located. The canopy when in full leaf has an estimated average density of 0.8. Small quantities of leaves, twigs, and other debris compose the only ground cover, and mineral soil is exposed in many places. The soil of the A horizon, which is 6 inches in depth, is a gray to light-brown silt loam that, except in the upper one-quarter inch, contains little humus.

The plantation site was formerly a gullied and sheet-eroded old field. Seedlings of black locust (*Robinia pseudoacacia*) and Osage-orange (*Toxylon pomiferum*) were planted in alternate rows in 1910 to control erosion and reclaim the land. The trees were originally spaced 6 feet apart, but the stand has been reduced from time to time by removal of the larger trees for fence posts. The crown canopy when in full leaf has an average density of about 0.9. Leaf litter is scant, but a ground cover of weeds, grasses, and tree sprouts is well established and is more than 50 percent complete. The area has suffered somewhat from light fires and from winter grazing; and the soil, a gray silty clay loam in the upper 5 inches, is rather compacted. Dark leaf mold composes the upper one-quarter inch of soil.

Rainfall [5] during the 2-year study period was above normal, totaling 130.70 inches, or 25.08 inches (23.7 percent) more than the average for the locality. Normal rainfall was exceeded by 20.07 inches during the first year of the study and by 5.01 inches during the second.

Rainfall was especially heavy in December and January of the first year and in February of the second year. Rainfall during December 1931 totaled 14.05 inches, an excess of 8.71 inches. A total of 38.41 inches of rain fell during the period November 1931-February 1932, inclusive, which was more than 100 percent above normal. During the second year of the study rainfall was 26 percent above normal for the period November to March, inclusive, in spite of monthly deficiencies in November and January. Excess of rainfall during the winter months tends to give rise to especially critical erosion conditions, because during the winter cultivated soils are more exposed to the elements and plant cover is least protective.

Table 1 shows for each month of the study period the number of rains and the total rainfall, and classifies the rains, by months, according to quantity of precipitation. During the 2 years there were 103 rains,[6] varying in quantity of precipitation from 0.03 inch to 5.32 inches.

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[5] In this region precipitation occurs almost exclusively as rainfall. Annual snowfall totals usually only a few inches.

[6] This total is the number of individual rains or series of rains for which run-off and erosion records were obtained. Records were obtained for individual storms when possible, but sometimes a single record had to suffice for a succession of rains extending over several days; of the 103 records, 82 are for single storms.

A number of the heavier rains were of comparatively short duration. On 16 occasions a rain of from 2 to 4.17 inches fell in less than 24 hours. On January 12, 1932, a 4.17-inch rain fell in 14 hours. On 15 occasions 0.50 to 0.80 inch of rain fell in 15 minutes, and on 4 occasions 0.85 to 1 inch of rain fell in 30 minutes. In one rain totaling 2.44 inches, 1.30 inches fell during three periods of only a few minutes each.

Of the total 2 years' precipitation 28 percent occurred as torrential rainfall and 20 percent occurred as rainfall of moderate intensity.[7]

The number of rains that caused run-off and erosion from the cultivated and barren plots was much greater than the number of rains that had this effect on plots with a plant cover. A total of 90 rains caused run-off from the barren plots and from the cultivated plot on which the rows paralleled the slope, and of these 89 caused erosion from the former and 87 from the latter. Almost as many rains produced run-off and erosion from the cultivated plot on which the rows followed the contour. From the scrub-oak plot 54 rains caused run-off, and of these 38 caused erosion. Rains thus resulting on the forest plantation plot numbered 38 and 31, respectively. Run-off from the Bermuda grass plot was caused by 33 rains, but only 14 of these removed soil from the plot. Soil and water losses were least frequent on the broomsedges and oak forest plots, run-off being caused by only 29 rains on the former and by only 32 rains on the latter. For a number of hours after certain rains small quantities of water seeped into the catchment tank of each of the forest plots from saturated leaf litter which overhung the lip of the tank. This slow seepage possessed little or no power to erode. As is shown in figure 3, out of 32 rains causing run-off only 8 caused erosion from the forest plots, whereas out of 29 rains causing run-off 16 caused erosion from the broomsedge plots.

[7] Rainfall was classified as follows: Torrential, at a rate of more than 0.75 inch per hour; moderate, at a rate of 0.40 to 0.75 inch per hour; gentle, at a rate of less than 0.40 inch per hour.

TABLE 1.—*Number of rains and quantity and distribution of rainfall, by months, during the 2-year study period*

Month	Rains or series of rains [1]	Total rainfall	Deviation from 46-year average [2]	Rains classified according to quantity of precipitation									
				Less than 0.25 inch		0.25 to 0.99 inch		1 to 1.99 inches		2 to 2.99 inches		3 inches or more	
	Number	*Inches*	*Inches*	*Number*	*Inches*	*Number*	*Inches*	*Number*	*Inches*	*Number*	*Inches*	*Number*	*Inches*
FIRST YEAR—OCTOBER 1931 TO SEPTEMBER 1932, INCLUSIVE													
October	2	1.37	−1.27	1	0.05			1	1.32				
November	5	6.89	+3.04	1	.23			3	4.54	1	2.12		
December	9	14.05	+8.71	1	.18	2	1.01	4	5.59	1	2.11	1	5.16
January	8	10.47	+5.70			5	2.46	1	1.67	1	2.17	1	4.17
February	6	7.00	+2.73	2	.29	1	.28	1	1.00	1	2.04	1	3.39
March	5	4.64	−1.90	2	.25	1	.86	2	3.53				
April	5	4.59	−.88	1	.03	2	1.29	1	1.09	1	2.18		
May	4	.57	−3.96	4	.57								
June	4	4.82	+.49			3	2.02			1	2.80		
July	2	5.99	+2.03							1	2.51	1	3.48
August	4	4.17	+.31			2	1.27	2	2.90				
September	3	8.11	+5.07							2	4.97	1	3.14
Total	57	72.67	+20.07	12	1.60	16	9.19	15	21.64	9	20.90	5	19.34
SECOND YEAR—OCTOBER 1932 TO SEPTEMBER 1933, INCLUSIVE													
October	5	4.59	+1.97	1	0.21	3	1.94			1	2.44		
November	4	3.02	−.92			3	1.61	1	1.41				
December	5	7.34	+1.80	1	.14	1	.34	2	2.89			1	3.97
January	4	2.75	−2.10	1	.14	2	1.41	1	1.20				
February	3	10.37	+6.11					1	1.55			2	8.82
March	4	8.23	+1.68			2	.57					2	7.66
April	4	4.98	−.55					4	4.98				
May	3	7.07	+2.51			1	.75	1	1.00			1	5.32
June	2	1.16	−3.21			2	1.16						
July	3	2.32	−1.56			3	2.32						
August	5	3.53	−.31	1	.18	3	1.96	1	1.39				
September	4	2.67	−.41			4	2.67						
Total	46	58.03	+5.01	4	.67	24	14.73	11	14.42	1	2.44	6	25.77
2-YEAR PERIOD													
Total	103	130.70	+25.08	16	2.27	40	23.92	26	36.6	10	23.34	11	45.11

[1] Of the 103 records, 82 are for single storms.
[2] Averages for 46 years based on U. S. Weather Bureau records of precipitation at Holly Springs, Miss., during the period October 1887–September 1933.

Data on the minimum quantities of rainfall that caused run-off from the various plots corroborate the data on run-off and erosion frequencies. Rains of only 0.13 and 0.14 inch caused run-off from the barren and cultivated plots, respectively; but only when rainfall totaled as much as 0.77 inch did surface waters wash from broomsedge and oak-forest plots. A rain of 0.62 inch was the lightest causing run-off from the forest plantation and Bermuda-grass plots, and the minimum rain causing run-off from the scrub-oak plot was 0.27 inch.

Marked differences were found among the various plots as to the percentage of precipitation in individual storms that ran off. Maximum run-off for a single rain from the two cultivated plots amounted to 96 and 77 percent of the rainfall, respectively, and the maximum from the barren old-field plots, amounted to 88 percent. Run-off from the cultivated plot on which the rows paralleled the slope exceeded 50 percent of the rainfall in 42 of the 103 rains, and exceeded 75 percent in 13 rains. Run-off from the barren old-field plots amounted to more than 50 percent of the rainfall in 30 rains, but on only three occasions did it exceed 75 percent. Run-off from the plots having a plant cover was comparatively small. During no storm did run-off from the oak-forest plots exceed 3 percent of the rainfall, and the maximum run-off from plots having a broomsedge cover was only 5 percent. Maximum run-off from a single storm was 9 percent for the forest-plantation plot, 21 percent for the Bermuda-grass plot, and 33 percent for the scrub-oak plot.

Run-off data for two individual storms clearly demonstrate that, under conditions comparable to those of the study, the ability of oak forest and broomsedge areas to absorb practically all rainfall holds, even during extremely heavy rains.

Storm no. 1, with a total rainfall of 4.05 inches,[8] was the major storm of a series of heavy rains that caused a disastrous flood in the Tallahatchie-Yazoo River Basin during January 1932. This rain was only moderately intense, but continued for 14 hours. Storm no. — (3.78 inches) is representative of heavy rains occurring on June 30 and July 1 that resulted in a flood by which lowland crops were damaged to the extent of $20,000. The latter storm was characterized by high intensities; twice during its progress 0.75 inch of rain fell in 30 minutes.

Of the 4.05 inches of rain falling in storm no. 1, 3.75 inches ran off the surface of the cultivated plots and 3.29 inches ran off the barren plots, whereas but 0.08 inch and a trace more than 0.08 inch ran off the surfaces of the forest plots and the broomsedge plots, respectively. In storm no. 2, run-off from oak-forest and broomsedge areas amounted to only 0.04 and 0.07 inch, respectively, in contrast with 2.89 inches from the cultivated field and 2.87 inches from barren abandoned land.[9] The run-off from cultivated lands and from grasslands was approximately 50 times that from forest.

Total run-off in relation to precipitation during the 2-year period is perhaps the best basis for comparing the absorptive capacities of the different land classes. Data on this point are summarized in table 2.

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[8] Quantity of rainfall registered by recording rain gage. The average quantity caught in all rain gages on the study area, as is shown in table 1, was 4.17 inches.

[9] In storm no. 2 the quantity of rain falling on the forest plots was slightly (8 percent) less than that falling on the other areas.

From the standpoint of water control and utilization, the significance of these run-off data is clearly shown by the contrast between the total surface water run-off per acre in 2 years of less than 4,000 cubic feet in oak forest and of 268,000 cubic feet on cultivated land.

Soil losses for the 2-year period are summarized in table 3.

The soil loss from the black locust plantation was undoubtedly smaller than the data indicate; disturbances on this plot during the first 5 months of the study caused abnormal erosion, as is indicated by the fact that almost 50 percent of the total soil loss occurred during that period. Soil losses from the barren and cultivated plots were enormous, and were proportionate with the run-off from these plots.

The ratio of the soil lost from the two cultivated plots to that lost from each of the oak forest plats was 4,300:1 and 1,528:1. The barren plots lost 3,519 times as much soil as did the forest plots. The erosion rate during the 2-year period indicates that the enormous rainfall of 1,789 inches would be required to erode a pound of soil from a forest plot, but that less than one-half inch of rainfall is required to erode that quantity of soil from a barren plot or from a cultivated plot with rows on a slope. The statility of the soils having a plant cover is further illustrated by a calculation as to the number of years needed to erode the upper 6 inches of surface soil under the different systems of land use.

TABLE 2.—*Total surface run-off and water absorption in relation to precipitation during the 2-year study period*

Plot	Rains [1]	Total precipitation [1]	Quantity of rainfall that—					
			Was absorbed			Run-off		
	Number	*Inches*	*Depth inches*	*Cubic feet per acre*	*Percent*	*Depth inches*	*Cubic feet per acre*	*Percent*
Oak forest [2]	103	134.21	133.18	483,443	99.23	1.03	3,739	0.77
Broomsedge field [2]	103	126.50	125.12	454,186	98.91	1.38	5,009	1.09
Black locust-Osage-orange plantation	97	112.05	109.85	398,756	98.04	2.20	7,986	1.96
Bermuda grass pasture	92	105.66	101.68	369,098	96.23	3.98	14,447	3.77
Scrub-oak woodland	102	127.54	117.52	426,598	92.14	10.02	36,373	7.86
Barren abandoned land [3]	103	129.21	67.51	245,061	52.25	61.70	223,971	47.75
Cultivated land (cotton):								
Rows on contour	103	131.38	69.68	252,938	53.04	61.70	223,971	46.96
Rows on slope	99	126.89	53.04	192,535	41.80	73.85	268,076	58.20

[1] Differences shown are due to the fact that on 4 plots experimental conditions were seriously disturbed during the first 3 months of the study by the vertical displacement of improperly anchored catchment tanks caused by a few heavy rains, data for these storms being omitted because of their incompleteness or inaccuracy.

[2] Run-off and erosion data based on average of duplicate plots for the first 6 months of the study.

[3] Run-off and erosion data based on average of duplicate plots for the first 14 months of the study.

TABLE 3.—*Soil erosion during the 2-year study period*

Plot	Total rainfall	Total run-off	Soil lost— Per plot	Soil lost— Per acre		Relative quantities [1] of soil eroded	Rainfall required to erode 1 pound of soil per plot	Surface soil eroded	Years required at existing rate to erode 6 inches of topsoil
	Inches	*Inches*	*Pounds*	*Pounds*	*Tons*		*Inches*	*Inches*	*Number*
Oak forest	134.21	1.03	0.075	91	0.05	1	1,789.47	0.0003	40,000
Broomsedge field	126.50	1.38	.305	369	.18	4	414.75	.0011	10,909
Black locust-Osage-orange plantation	112.05	2.20	1.676	2,028	1.01	22	66.86	.0062	1,935
Bermuda grass pasture	105.66	3.98	.311	376	.19	4	339.74	.0012	10,000
Scrub-oak woodland	127.54	10.02	1.089	1.318	.66	15	117.12	.0040	3,000
Barren abandoned land	129.21	61.70	263.961	319,393	159.70	3,519	.49	.9776	12
Cultivated land (cotton):									
Rows on contour	131.38	61.70	114.600	138,666	69.33	1,528	1.15	.4244	28
Rows on slope	126.89	73.85	322.472	390,191	195.10	4,300	.39	1.1943	10

[1] In terms of the minimum quantity of soil eroded from any plot.

The outstanding differences in the quantities of run-off from bare and vegetation-covered soils are significant in relation to stream-flow and flood problems, since flashy surface run-off composes the bulk of flood volume. During the 2-year period, the indicated run-off from an acre of cultivated land totaled 6 acre-feet, while run-off from an acre of forest land amounted to but little more than 1 acre-inch.

The ability of soils having a forest or grass cover to absorb practically all the rainfall demonstrates that such vegetation is an invaluable ally in the storage and retention of water that otherwise would form destructive surface flow. It appears probable that forest and grass cover exert almost their maximum effect on soil absorptiveness in the silt loam uplands of Mississippi, a section of fine-textured surface soils underlain by strata having great storage capacity.

Rainfall absorbed from the surface is not necessarily long delayed in reaching the streams; the delay is conditioned by several factors, especially the structure and character of the soil and of underlying materials. In this section, however, there is every reason to believe, rainfall once absorbed at the surface is sent deeply into the soil mass and is too long delayed in its appearance as seepage to figure conspicuously in flood stages. The upper soil layers are underlain largely by pervious deposits hundreds of feet deep. The silt and clay loams composing the upper soil horizons are themselves capable of retaining fairly large quantities of rainfall, according to observations made in road cuts and gully exposures after single rains. In such places, in which the depth of penetration by percolating water can be traced, invariably water appears as slow, lateral seepage for days after the heavy rains.

The huge soil losses from cultivated and other bare lands are indicative of the hazards involved in converting even moderate slopes, in the silt loam uplands of Mississippi, from forests to a bare-land type of agriculture. Although rainfall was abnormally abundant during the study period it is believed that the soil-loss figures are conservative, inasmuch as the gradient of the plots was moderate, their slopes were uniform, and their length was slight. These data substantiate earlier observations to the effect that the cultivable life of such upland soils ranges from 5 to 20 years only. It is doubtful that

such hasty exploitation of these soils, which required ages of weathering to produce, adds much to the economic well-being of the landowner; obviously, it does not conduce to public welfare.

That forestry, pasture development, and the production of forage cover crops are types of land management deserving wider usage is also implied by the results of this study. It appears probable that on land having a plant cover of any of the types studied, the rate at which erosion is occurring is well within that at which soil is being formed by natural processes.

The study has disclosed evidence on several points relating to forest management. The data indicate that an inferior cover of scrub oak possesses distinct value for the protection of watersheds. They bring out also the extent to which the protective efficiency of forest cover can be reduced by annual fires and other abuses. Thus the scrub-oak stand, which has replaced old-growth oak forest, permitted a soil loss 15 times as great as that permitted by normal forest cover and a rainfall loss by direct run-off 10 times as great as that permitted by such cover. A cover of black locust and Osage-orange, established less than 23 years previously, was found to have converted an eroded abandoned field into a stable site capable of absorbing 98 percent of the rainfall. Analyses of the soil of the planted area showed 3 percent of organic matter in the upper-6-inch layer, as great a proportion as occurs in the corresponding layer of virgin soil under oak forest.

Appendix B

EFFECT OF COVER ON FLOODS IN UTAH [10]

In 1923, disastrous floods occurred at Farmington and Willard, Utah. Mountain sides were gullied, farm property in the valley was destroyed, and six people were killed in Farmington Canyon. The damage to town and farm property at Willard was between $75,000 and $85,000. The report of Governor Dern's special flood commission describes conditions in this region and the causes of floods as follows:

Paul and Baker, reporting on the 1923 floods of northern Utah, attributed the floods to destruction of cover at the heads of stream courses.

Again in 1930 and 1932 increasing numbers of areas in Davis, Salt Lake, and Utah Counties were flooded. Newspapers estimated the damage at more than $1,000,000. The Red Cross report on floods in these counties in 1930 states that 179,200 acres of high-priced truck and orchard land was flooded and 295 acres of such land rendered completely useless, that 134 families were left homeless. It cost Utah about $100,000 to clear the State highway.

By careful examination after the floods of 1930 a special flood commission established [11] that the silt-laden flood water had collected chiefly on small areas of private land at the heads of the drainages where the vegetative cover had been seriously depleted or destroyed by overgrazing, by fire, and to some extent by timber cutting.

[10] See also Floods and Accelerated Erosion in Northern Utah by Reed W. Bailey; U. S. Dept. of Agric. Msc. Pub. 196, 1934.

[11] Torrential Floods in Northern Utah, 1930. Report of Special Flood Commission. Utah Agr. Expt. Sta. Circ. 92. 1931.

The west slope of the Wasatch Mountain range in the Centerville-Farmington section is, in the main, well covered with vegetation except on localized areas. These are chiefly along the lower mountain front, and on the upper slopes, and in the basins at the heads of the canyons which were flooded, where the plant cover has been more or less depleted since the settlement of the section. The intermediate mountain slopes for the most part are well covered with a relatively dense stand of brush.

The lower slopes of the mountain ridges between the principal canyons support a thin stand of plants consisting chiefly of downy chess, annual and short-lived perennial weeds, and scattered clumps of oak brush. This condition can be noted in the lighter colored part of the slope making up the mountain face below the upper level of Lake Bonneville. Judging from a few preserved or restored remnants that are in nearly the original condition—such as in cemeteries and field borders within the general region and on the ungrazed sections of City Creek and the Fort Douglas Military Reservation in the foothills near Salt Lake City—the former cover consisted of a fairly dense stand of bunch grasses, interspersed with sagebrush and more or less scattered patches of oak brush and other shrubs. The cover on the lower mountain front was heavily depleted by overgrazing and repeated fires many years ago and has been replaced by the present thin stand of vegetation which has continued to be heavily grazed and, at intervals, burned over.

Torrential superficial run-off on slopes having sandy loam soils such as those on the mountain slopes in the Centerville-Farmington section, leaves its telltale marks of gullies and sheet erosion and disturbance of the surface litter to be observed for several months or years thereafter. The presence of numerous gullies on a slope is unmistakable evidence of torrential run-off. The absence of gullies shows that run-off was slight and neither torrential nor rapid. If dead leaves and other light material on the surface of the ground are little disturbed it indicates that run-off was so slight and so slow as not to disturb this lightweight material or that run-off occurred only as slow seepage underneath the litter. It is obvious that a run-off too slight and too slow to disturb plant litter materially would not produce a sudden high head of water of relatively short duration, such as characterized the 1930 floods in the canyons in the Centerville-Farmington section.

When these criteria are applied, it is evident that several miniature floods which cut numerous gullies formed on the sparsely vegetated areas of these lower mountain slopes. These small floods, however, did not contribute to the main floods, since the run-off did not empty into the main canyons, but flowed out over the old lake terraces between the canyons, where small alluvial fans were deposited. On the other hand, no concentrated run-off or erosion occurred on the well-vegetated but other similar slopes in the ungrazed foothills of City Creek and the Fort Douglas Military Reservation, although it was evident that the rainfall was equally heavy in both the flooded and nonflooded localities.

The vegetation in the heads of the canyons above the oak zone is variable both as to kind and quantity. A conspicuous feature is the presence of areas, varying in size from less than an acre up to 30 to 40 acres, that have been practically denuded of vegetation, plant litter,

and mellow topsoil. Areas with a fairly dense cover of snowbrush and thickets of scrubby aspen, having considerable litter and a deep humus soil, constitute the other extreme. Between these extremes are open stands of shrubs, including principally sagebrush, chokecherry, snowberry, and aspen. The vegetation increases in quantity more or less progressively outward from the heavily depleted places until eventually a dense cover is reached.

The more gently sloping parts of the stream bottoms and the benchlike features of the head of Ford Canyon, which have a gradient of 4° to 10°, except where strips or portions of the irregularly shaped patches of aspen extend to them from adjacent steeper slopes, are the most heavily devegetated. Practically the only vegetation in these openings in the summer of 1930 consisted of occasional stubby remains of shrubs, including elderberry, snowberry, and willows, a thin stand of coneflower, lupine, and a few annuals and other plants, all of which had been grazed almost to extinction by midsummer of that year. This vegetation occupied considerably less than one-tenth of the surface of the ground. The soil varies in depth from 2 to 25 feet or more, but in the exposed places is compacted and wholly lacking in litter cover; a surface horizon high in organic matter is wanting, and the surface is scarred by frequent gullies varying from a few inches to 2 to 5 feet in depth and width.

Much the same depletion exists between the trees in the more open parts of the broken patches of open-to-dense stands of aspen which extend from the steeper slopes to the bottoms and gentler slopes. Stubs of snowberry and other shrubs and occasional plants of coneflower and other species of inferior palatability to livestock made up the very limited undergrowth. The abundant leaf litter normally found on the ground on such sites was absent, and the surface soil was very compact. In places on the slopes where the more open stands of aspen give way to small thickets of sapling size, there is little undergrowth, owing to the dense shade and extreme competition for available soil moisture; but the aspen trees themselves are so numerous as to afford a good cover and have produced an abundant litter which is fairly intact. However, the area occupied by these aspen thickets is relatively small. Between the areas characterized by these more extreme conditions in the aspen type are those conditions intermediate in tree-growth density and in depletion of undergrowth and loss of litter cover.

Conditions vary where the shrubs other than snowbrush predominate in the cover. Cover of any kind is very sparse or almost lacking on such places as sheep bedding grounds, ridge tops, and heavily used passageways leading from one drainage to another. In the more inaccessible places there are a few small, fairly dense patches of vegetation consisting chiefly of thickets of chokecherry or of sagebrush 2 to 4 feet in height, interspersed with clumps of snowbrush, with a fair undergrowth of herbaceous plants. However, the major portion of the cover is intermediate between these two extreme conditions and consists of an open stand of shrubs with a sparse stand of herbaceous undergrowth. The consequence is that in these places 70 to 95 percent of the ground between the shrubs is barren of vegetation, and there is but little litter cover.

The patches of snowbrush are more comon on the drier, south-facing slopes where this species occurs in almost pure stands. This

shrub generally forms a very dense growth. Except on a few places where there has been excessive trailing by the livestock in their movements from one drainage to another, or small burned areas, the snowbrush type provides a heavy, little-disturbed plant cover, having a mellow soil 1 to several feet in depth with a substantial litter of decaying plant material.

About one-fourth of the total area of the upper zone at the head of Ford Creek, consisting of not more than a thousand acres, is nearly denuded of vegetation and litter. The most densely covered areas amount to approximately one-fourth to one-third of the total area, and on the remainder the plant cover and surface soil are intermediate.

It was strikingly evident that the 1930 floods originated on the barren or nearly barren areas in the upper zone. The freshly eroded main flood channel in the bottom of each canyon extended continuously from the upper zone to the mouth. Most of the numerous gullies of all sizes which joined to form the main channel, when traced to their source, were found to originate on the areas where there was little or no vegetation. It was apparent that here the rain, falling on a surface little protected by vegetation and with a soil in poor condition to absorb moisture, instead of running off slowly or being absorbed by the soil, quickly collected in numerous streamlets which increased rapidly in size, velocity, and erosive power as they rushed down the slopes, cutting gullies as they swept along. In some instances gullies which started near the top slope in Ford Canyon, converged only a few hundred feet farther down to form channels nearly 20 feet deep. Even the gentler 3° to 5° slopes, when sparsely vegetated, had numerous gullies. The frequency, size, and distribution of the gullies on the parts denuded of vegetation show clearly that a large volume of water quickly accumulated on them.

Progressively outward from the barren areas, as the vegetation improved in density, gullies decreased in size and frequency with increase in vegetation, until in dense brush, or where the brush and free cover was well augmented by grasses and weeds or a substantial litter cover or both, there was no indication of torrential run-off. Under the dense stands of snowbrush there were no gullies and the litter cover was barely disturbed, whereas only a short distance away in the overgrazed, scanty sagebrush stands, gullies were numerous and frequent, although less so than on the depleted slopes. Although practically no gullies originated in the aspen thickets, those formed on barren areas above continued on down in lessened size through the more open aspen stands.

The heads of all of the tributaries of Ford Canyon as well as the other canyons which were flooded presented essentially identical features. The only gully which extended down the slope through the oak zone into Ford Creek was found to originate in a small, gently sloping basin near the top of the broad ridge between Ford Canyon and Davis Canyon. The entire head of this tributary drainage has a cover of dense aspen, chokecherry, and shrubs, except for an opening of not more than 12 acres in the basin. A corral for handling sheep has been built in this opening, and there the heavy grazing and trampling incident to the use of the corral has resulted in almost complete denudation. The evidence was clear that all the water necessary to erode a channel 15 to 20 feet in depth and width down the canyon slope in the oak zone, had accumulated on this denuded area.

The upper zone of Parrish Canyon watershed is smaller than that of Ford Canyon, approximately 700 acres. Also the relief of Parrish Canyon is less steep, the bottoms of its two principal forks are relatively broader than those of Ford Canyon, and there is a larger proportion of gently sloping canyon bottom and basinlike area. Although such conditions are less favorable for a quick accumulation of run-off several mud flows approximately equal in size to those in Ford Canyon swept down Parrish Canyon in 1930. The sizable flood from the smaller, less steep Parrish Canyon watershed is accounted for by a relatively greater proportion of devegetated area in it as compared with that in Ford Canyon. Approximately one-third of the area of the upper zone in Parrish Canyon was classified as extremely bare, as compared with one-fourth of the area in Ford Canyon. This unfavorable condition was not ameliorated by the fact that the remaining area in upper Parrish Canyon is on an average in somewhat better condition as to soil and vegetation than that in Ford Canyon.

The steep, well-vegetated intermediate side slopes of the canyons contributed practically no run-off to the floods which swept down the main stream channels. Ford Canyon is typical. The slopes of this canyon from just above the mouth to within a mile or less of the summit of the Wasatch Range support a substantial cover of brush, principally oak brush and bigtooth maple, with patches of white fir, Douglas fir, and aspen on the north exposures. The conifers and aspen stands ordinarily have an admixture of brush including snowbrush, myrtle boxleaf, and other species. The vegetation in this zone is normally too dense and the slopes too steep to afford ready grazing, and for that reason it is but little utilized by livestock and is not overgrazed except on occasional small openings probably originally caused by fire. The soil is fairly deep and rich, has a deep humus layer, and is overlain by several inches of litter consisting of shed leaves and other plant material in various stages of decomposition.

Evidence of any material contribution to the flood which swept down Ford Canyon from the dense vegetation of the oak zone, or of any run-off of consequence originating in this plant cover, was conspicuously lacking. The channel cut in the canyon by the flood was not appreciably deeper or wider at the lower end than it was where it entered the upper edge of the zone. No gullies originating on the adjacent steep, brush-covered slopes led into the flood channel. A single gully or wash that originated under different cover conditions on the upper edge of the canyon slope was continuous through the heavy vegetation but showed no evidence of receiving much if any additional water along its course. The litter and debris on the vegetated slopes extended down to the very edge of the main channel and showed no evidence of having been disturbed by running water during the torrential rainstorms, except in the small openings in the oak type previously referred to.

These openings bear witness to the fact that the rains were fully as heavy throughout the oak zone, as a whole, as on the parts of the watershed where the floods originated, and show the efficacy of plant cover in checking run-off and erosion. These small openings, practically barren of vegetation, were gullied during the storms in a manner similar to that evident on barren slopes both below and above the oak zone. Even though these openings are small—all that were examined were less than an acre in area—the heavy rain which fell

on them had gathered quickly into streamlets which eroded gullies. However, on reaching the dense brush cover, this run-off was quickly dissipated over the slope, and the soil and other debris which had been picked up was dropped in the brush and litter. It seems very evident that in spite of torrential rainfall, the floods in Ford Canyon did not gather in the heavily vegetated oak zone comprising about three-fourths of the area of the watershed, but came from the one-fourth of the drainage that lies farther upstream.

The oak-brush zone of three other canyons that were flooded in the Farmington-Centerville section all presented essentially the same picture as that in Ford Canyon. There slopes differ some in gradient, but throughout this zone there was no evidence of heavy run-off or erosion except in the channel in the bottom of each of these canyons.

Further evidence of the effectiveness of a plant cover in checking erosion and run-off of flood proportions is found in Centerville Canyon, immediately south of Parrish Canyon. This drainage is similar to Parrish Canyon as to shade and topography but is slightly larger in area. Its watershed, in addition to having the heavy brush cover in the intermediate zone, is for the most part well vegetated in the upper zone. The town of Centerville has acquired approximately half of the land in the upper zone for watershed protection, and has arranged with the owners of the remainder of the land for restricted grazing use. Private owners must not graze more livestock on the entire watershed than they would normally graze on their own land. Consequently the upper zone is not as depleted of vegetation as are the canyons farther north. The only injured spots are a few small favorite congregating places for cattle. Centerville Canyon did not produce a flood of any consequence. After each of the heavy storms the depth of flow in this canyon increased several feet, remaining so for several hours after the high floods in the canyons just to the north had passed. It is reasonable to suppose that the torrential rains extended over the watershed of this canyon. Small denuded patches on its slopes were gullied, having the same marks of torrential rainfall and run-off as the denuded areas on the watersheds farther north. Thus it seems evident that the better plant cover at the head of Centerville Canyon was effective in preventing a flood in this drainage.

It is evident that the areas which are now practically bare in both Ford and Parrish Canyons formerly supported a much heavier and considerably different vegetation. The bottoms and benches are potentially the most favorable sites for plant growth because of deep soil accumulation of soil moisture from winter snow, and the protection that is afforded against drying winds in summer. Decadent remnants of shrubs indicate the former presence of a denser plant cover. Similar sites in other localities within the region of the floods, where practically the original plant cover has been maintained, support a heavy stand of grass, other herbs, and shrubs; occasional similar secluded places on watersheds, adjacent to those which flooded, now have a cover of such vegetation that occupies 40 to 60 percent of the surface of the ground and have a good cover of litter and a surface layer of soil high in organic matter.

The scanty plant cover on the nearly denuded areas, together with evidence from otherwise similar moderately or little grazed areas, indicates that the sagebrush and other shrub types, exclusive of the snowbrush, also formerly supported a much heavier stand of herba-

ceous plants. It is probable that the total vegetation in many places in these types formerly occupied 40 to 60 percent of the surface and afforded a substantial plant litter. This is in sharp contrast with the present cover, which in 1930 occupied sometimes less than 10 percent of the surface and which provided little or no plant litter.

The testimony of numerous nearby residents who have known the watersheds for many years substantiates the conclusion that the areas that now are practically denuded or have a sparse cover were formerly well vegetated.

Causes of depletion of the vegetation in the heads of the canyons which were flooded are convincing. It was apparent from conditions which existed when the area was examined in 1930 that the number of animals being grazed in both drainages was and for some years had been far in excess of what such range could be expected to support without severe overgrazing. Observations in July 1930, when more than half of the grazing season remained, showed that the livestock on the area at that time had consumed most of the fairly choice vegetation and were subsisting on species normally little used on similar ranges when moderately grazed. According to information supplied by the owners of the lands, the head of Ford Canyon had been as heavily or more heavily stocked, with sheep and a few cattle for not less than 10 years prior to 1930. Parrish Canyon has been grazed chiefly by cattle. Both the openings and the aspen patches in the bottoms and on the terraces of canyons are near the streams where livestock come to water, and because of regular surface conditions, the shade afforded by the trees, and some forage growth each year, are favorite congregating, bedding, and grazing places for both sheep and cattle. Consequently these areas are extremely heavily grazed and trampled. The livestock are forced to utilize all but the most inaccessible areas because there is not sufficient forage on the more choice areas. The vegetation which remains is low in palatability and is that which commonly remains on or encroaches on overgrazed range. Several patches on the drier slopes have been swept by fire, and subsequent overgrazing has prevented the restoration of a normal plant cover. The more favorable sites are usually too moist to be burned; at least, there was no evidence at the time of examination of recent burns.

These results afford evidence of the value of plant cover in regulating surface run-off and controlling erosion. Recent serious floods in several canyons in the Centerville-Farmington section of northern Utah cut to extraordinary new depths in the previously undisturbed sands and gravels of the deltas and terraces of ancient Lake Bonneville. They also deposited quantities of debris and sediment on the former bottom of the old lake far in excess of the previous normal rate of deposition, and thus showed that the floods in these canyons were unprecedented, at least in modern times.

The floods followed rains which were torrential in character but by no means unique in volume or rapidity of fall. Their origin, as shown by excessive gully erosion, is traced primarily to relatively small areas, in the heads of canyons, which in recent times have been depleted of vegetation and denuded of plant litter, chiefly by overgrazing but to some extent by fire. The torrential rains did not cause run-off sufficiently concentrated to cause gullying on thickly vegetated parts of the watersheds, regardless of the steepness of

slopes, although evidences of erosion on small barren areas in these parts indicate that the rainfall was approximately equal on both the well-vegetated parts and the depleted areas at the heads of the canyons.

It is concluded upon the evidence found on the watersheds that the floods which caused the recent radical departure from the normal post-Bonneville erosion and sedimentation in the canyons of the Centerville-Farmington area are directly attributable to the destruction, by overgrazing and fire, of the major portion of the vegetation and the concomitant loss of the plant litter and more porous topsoil on critical parts of the watersheds. There the soil and vegetation which had become established long ago, and had been maintained through thousands of years, had been, until recently, the means of controlling run-off and preventing excessive erosion. On slopes the relation between vegetation and soil and run-off represents a delicate balance. This balance was broken when excessive grazing and fire so reduced the plant cover that the ground became relative bare and the humus layer of soil was gradually eroded away. Furthermore, trampling had compacted the soil. On these denuded areas the run-off from cloudbursts was rapid, and the accumulated floodwaters channeled deep gorges down the entire length of the canyons and spread debris in the valleys below. This variation from the long period of relative quiescence is convincing evidence that the recent violent floods represent a distinctly accelerated rate of run-off and erosion, traceable to depletion of the plant cover.

Appendix C

DESCRIPTIONS OF MAPS PRESENTED BEFORE THE HOUSE COMMITTEE ON FLOOD CONTROL AT HEARINGS ON THE BILL H. R. 12517, MAY 21, 1936

Map 1 shows geographically the relative degrees in which timber and brush forests influence the stability of streamflow and the protection of watersheds. The three degrees of influence, major, moderate, and slight, are determined largely by major soil and slope conditions. To illustrate, in areas of steep mountainous land, where most of the soils are of a highly erosive character, forests are classed as having a major influence on watershed conditions. In areas of relatively low gradient and coarse sandy soils which absorb most of the water that falls on them, forests are classed as having only slight influence. The total area in which forests are classed as having major influence on watershed conditions—dark-blue-green on the map—is 308,000,000 acres; occurring principally in the mountain and Piedmont areas, and in the hills along the Mississippi River.

The area in which forests exert moderate influence on watershed conditions—the intermediate shade of green on the map—is 140,700,000 acres.

This classification is based on forest and brush covers only, not on areas once forested, but now largely cleared and used for farming, nor on other types of cover such as grassland, mountain meadows, sagebrush, etc.

Map 2 is the Reconnaissance Erosion Survey Map of the Soil Conservation Service, prepared in 1935 and published as part V of

the supplementary report of the land planning committee of the National Resources Board. This gives a quite detailed classification of erosion conditions. Water erosion of the more serious classes is found on the areas shown by red, lavendar, orange, buff, pink, yellow, tan, and brown. These areas combined aggregate 968,938,740 acres. Within this area more than 25 percent of the land has been affected by serious erosion. A comparison of this map with the others in this series shows a high degree of overlap of serious erosion areas with areas in which there are large numbers of submarginal farms. Much of the seriously eroding land is in submarginal farms. The proposed forestry program includes the conversion of these lands to forest management, and then development for timber production, wildlife, recreation, and stock grazing. Although limited areas are needed for exclusive use for recreation and wildlife, for the most part multiple use forest management is recommended.

Map 3: The control of erosion on the lands which are to continue in farm use is a matter in which other agencies than the Forest Service are primarily interested, and of course, comprises a very appreciable part of the needed land-use adjustment for water and soil conservation. The Forest Service interest is in nonfarmlands, and in those lands which it is agreed should be retired from farm use. These two classes of land aggregate about 1,064,000,000 acres, or about 56 percent of the total land area of the country (exclusive of territorial possessions). Map 3 shows the distribution of timber and brushland by dots. Each dot represents 10,000 acres of such land. There are 61,500 dots or 615,000,000 acres. The distribution of the remaining 449,000,000 acres which make up the balance of the 1,064,000,000 acres of forest or wild land is not shown in similar detail, but most of it is in the Western States.

The red areas on the same map are those in which a large amount of submarginal farms were found and reported upon by the land-planning committee of the National Resources Board in 1934. A total of 75,000,000 acres of submarginal farms was recommended by the National Resources Board for retirement. They largely occur within these red areas. This map shows that they are not solid blocks of farms, but to a large extent scattered farms interspersed with forest land.

The boundaries of the principal watersheds are also defined on this map, to show the distribution of forest land and submarginal farms on watersheds from which serious floods arise.

Map 4 is a composite map combining the areas of major watershed influence, most serious soil erosion and submarginal farms. This map was prepared in 1933 from the best data then available, and while it does not check fully with the latest erosion and submarginal farmland data, it does give a good general picture of conditions. The green indicates areas combining most serious soil erosion and forests of major watershed influence in accordance with the 1933 data; 162,774,000 acres falling in this class. The red is additional area in which forests are of major watershed influence making a total area of major watershed influence of 438,989,000 acres. The brown shows the additional forest which combined with the first class (the green areas) gives an aggregate area of most serious soil erosion of 282,201,000 acres.

Shown in tan color is the additional natural forest area over 75 percent submarginal for farm crops. A total of 482,630,000 acres are so classed, including the areas overlapping into the most serious soil erosion and major watershed influence areas.

The yellow shows the additional natural-forest area classed as 50–75 percent submarginal for crop use. Combined with the land in this class, which overlaps in the areas of most serious soil erosion and major watershed influence, there are 183,376,000 acres classed as 50 to 75 percent submarginal for farm use.

The blue is natural-forest area not of major watershed influence or serious soil erosion nor over 50 percent submarginal for farm crops.

This map concerns itself only with the timberland or lands which naturally supported a timber forest. It was prepared for a special purpose several years ago and does not show large areas of submarginal land in the Western States, brush forests, woodlands, sagebrush, and grassland areas on which overgrazing, fire, and ill-advised tillage have created conditions which call for essentially the same kind of remedial treatment (i. e., protection, revegetation, and multiple-use forest management), as the denuded timberlands and submarginal farms of the natural-timber-forest area.

Map no. 5 shows the present and recommended Federal forests in relation to the major watersheds. The dark-green areas are national forests formally proclaimed by the President of the United States. Those in the western half of the country were largely created out of unreserved public-domain land in the first decade of this century. Those in the Eastern United States have largely been acquired under the provisions of the Weeks law of March 1, 1911 (36 Stat. 961), which authorizes the Federal Government to acquire land for forest purposes on the headwaters of navigable streams, and which was amended by the Clarke-McNary Act of June 7, 1924 (43 Stat. 653), to permit acquisition of forest lands anywhere on the watershed of navigable streams, not only for watershed protection but also for timber production, thus creating opportunities to work out and demonstrate methods of forest management.

The pale-green areas are national forest purchase units hitherto approved by the National Forest Reservation Commission, and in which land-purchase work is now being conducted. When a sufficient part of the acreage in any of these units has been acquired and title vested in the United States, it will be proclaimed a national forest by Presidential action.

The orange areas are recommended additional Federal forests, from a study conducted for the National Resources Board in 1934. They are compiled from the State and regional recommendations of local forestry officials and field officers of the Forest Service and are subject to revision on the basis of national, as distinct from State and regional, requirements. They are, of course, also subject to revision as more detailed information is obtained on forest-land conditions in different parts of the country. Nevertheless, they may be considered as indicative of the pattern which national forests would make if forest acquisition were undertaken on the scale recommended by the Copeland report and the Forest Service report to the National Resources Board. The completion of the Federal purchase program as here outlined would involve the acquisition of 118,000,000 acres of forest land, of which 23,000,000 acres is in established purchase units

and about 20,000,000 acres in existing national forests in the West. The balance is within areas not now included within the boundaries of national forests or purchase units.

The total cost of this acquisition program is estimated at $740,000,000, including $310,000,000 for the purchase of mature timber as a basis for sustained yield communities, largely in the West. Aside from the part used for the acquisition of mature timber, acquisition funds are utilized largely for the purchase of cut-over and devastated forest land, restocking and second-growth areas, and submarginal farms. To a large extent these areas are of major watershed importance. This is particularly true because much of the land is in the high mountainous country where the heaviest rainfall occurs.

This map of present and proposed Federal forests does not show the entire Federal program formulated for the management of forest land in relation to water resources and flood control. Watershed and forest conservation is not confined, of course, to the establishment of national forests, but also includes cooperative programs with State and private forest owners for the protection and improvement of forest areas, as authorized by the Clarke-McNary Act of 1924 and amendments, and in State forest acquisition as authorized by the Fulmer Act of 1935. A map showing this cooperative program remains to be developed. Comparing map no. 5 with map no. 3, however, demonstrates that there are large areas of forest land and submarginal farms which do not fall within present or proposed Federal forests. Yet many of these areas have a high degree of interstate and national importance from a flood-control and water-conservation standpoint. This is particularly true of States like New York and Pennsylvania, where State programs of protection have been such that Federal programs have not been inaugurated. In other States, too, large areas important from an interstate and national standpoint have been left for State development with Federal cooperation rather than for full Federal development as national forests. The cooperative program includes, first, cooperation in protection from fire. This was initially authorized by the Clarke-McNary Act of 1924. Today 237,000,000 acres are under cooperative fire prevention as a result of this act, the Federal Government cooperating to the extent of about $1,574,042 yearly (average for fiscal years 1931–35, inclusive), against State expenditures of $3,116,143 and private expenditures of $973,644, making a total average expenditure of $5,663,829. An additional area of about 190,000,000 acres is yet to be brought under such protection.

Figures on the acreage burned annually are the best indication of the effectiveness of a fire-control program; on the national forests, during the period 1927–33, an average of 0.22 percent[12] of the total. The burning of the mat of fallen leaves and other litter over a large portion of the forest area causes greatly increased surface run-off and erosion and adds to the volume of floods and the amount of silting in reservoirs and stream channels. Data will be presented showing the relative run-off and erosion from burned and unburned forest areas and from other classes of land. The cost of adequate fire prevention on the total area of 427,000,000 acres of State and private land in need of such protection is estimated at $13,039,705, or from

[12] National Resources Board Report, p. 209. In the same period 1.88 percent of areas under cooperative protection, and 20.75 percent of unprotected areas, were burned over annually.

3 to 4 cents per acre. On the basis of a 25-percent direct contribution from the Federal Government, its share of the cost of a program for all the forest land in need of protection would be $3,346,568 (including administrative expense), or an increase of $1,772,526 over the average appropriation for the period 1931–35.

While fire prevention is the principal need as regards run-off and erosion control on areas now forested, control of grazing, both of wild game and domestic stock, is another necessary requirement in the control of erosion and excessive run-off on forest lands. Still other measures, such as reforestation, terracing, and check dams, are to supplement fire protection, regulated timber cutting and grazing, and wildlife management, on seriously eroded areas and submarginal farms.

On areas which private ownership profitably can manage and at the same time maintain favorable watershed conditions, given reasonable public aid, the need for public acquisition and public forest management is not urgent, unless some special public interest or service dictates such action. But on areas which cannot be managed profitably by private enterprise and on which the public interest requires forest management for watershed protection and other purposes, public ownership is indicated. It is such areas that are being acquired or are proposed for acquisition as national forests or for State forests under the Fulmer Act.

From the standpoint of water-resource conservation and flood control, a forestry program based upon the information summarized in these maps and on other available data regarding the influence of forests on water supply and run-off involves (1) increased cooperative forest protection, (2) acquisition of additional lands for national forests and the initiation thereon of protection, revegetation, erosion control, and other flood-prevention and water-conservation measures, and (3) acquisition of lands for State forests as authorized by the Fulmer Act.

The above-described maps are colored and somewhat complex to reproduce in black and white for printing. They are on file in the Forest Service.

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